UNCLASSIFIED

AD NUMBER

AD826208

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to DoD only; Administrative/Operational Use; JAN 1968. Other requests shall be referred to NASA, Marshall Space Flight Center, Huntsville, AL.

AUTHORITY

USAEDC ltr, 12 Jul 1974

THIS PAGE IS UNCLASSIFIED

AEDC-TR-67-215

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-06)

N. R. Vetter

ARO, Inc.

January 1968

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

LARGE ROCKET FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-06)

N. R. Vetter
ARO, Inc.

AF - AEDC
Arnold AFS Tenn

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under contract AF 40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on August 22, 1967 in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on September 19, 1967.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of NASA/MSFC (I-E-J), or higher authority. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

Harold Nelson, Jr.
Captain, USAF
AF Representative, LRF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted on August 22, 1967 in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility, Arnold Engineering Development Center. The firings were accomplished during test period J4-1801-06 at pressure altitudes from 103,000 to 108,000 ft at engine start. The objectives of the test included the evaluation of (1) thrust chamber ignition characteristics with low augmented spark igniter mixture ratio and (2) the effects upon engine starting transients of minimum fuel pump inlet pressure and thrust chamber resistance for first orbit restarts with maximum starting energy. Satisfactory engine operation was obtained. The accumulated engine firing duration was 70.3 sec.

CONTENTS

APPENDIXES

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine (S/N J-2052) with a Douglas Aircraft Company S-IVB battleship stage has been in progress since July 1966 at AEDC, in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for NASA Apollo Program. The four firings reported herein were conducted during test period J4-1801-06 on August 22, 1967 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-IVB/S-V thrust chamber ignition characteristics with low augmented spark igniter mixture ratio and engine starting transients for first orbit restarts with maximum starting energy. These firings were accomplished at pressure altitudes ranging from 103,000 to 108,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start.

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at the AEDC. The results of the previous test period are reported in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 Rocket Engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants, and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage with the J-2 engine is shown in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively. All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5 and Ref. 3), features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct), before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the static test stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility vent system.

2.2 TEST CELL

Test Cell (J-4), Fig. 2, is a vertically oriented test unit designed for static testing liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen

(gaseous and liquid), liquid oxygen, and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air inleakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber and crossover duct. Helium was routed internally through the tubular-walled thrust chamber and crossover duct.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of

(1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units, (2) voltage substitution for the thermocouples, (3) frequency substitution for shaft speeds and flowmeters, and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (Microsadic®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequence are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Table V presents the engine purge operations during the terminal countdown and immediately following the engine firing.

Temperature conditioning of the thrust chamber and turbine crossover system was accomplished as required, using the facility-supplied conditioning system.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Four firings were conducted during test J4-1801-06 on August 22, 1967 for a total firing duration of 70.3 sec. All firings were in support of the S-IVB/S-V J-2 engine developmental program. Thermal conditioning of the thrust chamber and turbine crossover system was accomplished to simulate the flight engine thermal conditioning predicted for (1) J-2 engine first burn and (2) engine restart after a 90-min orbit. A propellant utilization valve excursion from null to the full-closed position was conducted during the 30-sec firings 06A and 06C, effectively changing the oxidizer-to-fuel ratio from 5.0 to 5.5. Firings 06B and 06D (each of 5-sec duration) were conducted with the propellant utilization valve fully open. Firings 06A and 06C were preceded by 3-sec fuel leads; 06B and 06D were preceded by 8-sec fuel leads.

Specific test objectives and a brief summary of results obtained for each firing are presented as follows:

Firing	Test Objectives	Results
06A	Evaluate the effects of low start tank energy and -200°F thrust chamber upon high level fuel pump stall for a S-IVB/S-V first burn.	A minimum stall margin of 600 gpm was realized in the region above 5500 gpm.
06B	Evaluate the effects of minimum fuel pump inlet pressure upon low level fuel pump stall for a S-IVB/S-V first orbit restart with maximum starting energy.	A minimum stall margin of 1600 gpm was realized in the region below 5500 gpm.
06C	Evaluate thrust chamber ignition characteristics for a S-IVB/S-V first burn with low augmented spark igniter mixture ratio.	A thrust chamber pressure of 100 psia was attained at t_o + 1.035 sec. VSC was measured for 95 msec during the ignition transient.

Firing	Test Objectives	Results
06D	Evaluate the effects of thrust chamber resistance upon engine starting characteristics for a S-IVB/S-V first orbit restart with maximum starting energy.	A thrust chamber pressure of 100 psia was attained at t_0 + 1.008 sec. VSC was measured for 18 msec during the ignition transient. The gas generator outlet temperature first peak was 1970°F.

The presentation of the test results in the following sections will consist of a discussion of each engine firing. The data presented will be that recorded by the digital data acquisition system, except as noted.

Specific test requirements and results are summarized in Table VI. Start and shutdown times of engine valves are presented in Table VII. Included in Table VII are prefiring valve times obtained from the final sequence run. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-06A

Firing 06A was of 30-sec duration with a propellant utilization valve excursion from null to fully closed at t_0 + 13 sec. The firing was preceded by a 3.0-sec fuel lead. A summary of engine start requirements and test results is presented in Table VI.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 9. The initial gas generator outlet temperature peak was 1830°F. Initial main oxidizer valve second stage movement occurred at t_0 + 1.005 sec. Thrust chamber ignition occurred 1.055 sec after t_0, and engine vibrations (VSC) were recorded at t_0 + 1.053 sec for 24 msec.

Transient fuel pump head/flow data for firing 06A are compared with the stall inception curve in Fig. 10. In the particular region of investigation for this firing (above approximately 5500 gpm), a minimum stall margin of 600 gpm was realized.

A summary of start and shutdown times for engine valves during 06A is shown in Table VII. All valve operating times were consistent and normal.

Engine chamber pressure and test capsule ambient pressure for firing 06A are shown in Fig. 11. The effects of the propellant utilization valve excursion occurred at approximately t_o + 13 sec, at which time engine chamber pressure increased from 690 to 780 psia. Thermal conditions of engine components are shown in Fig. 12.

Engine steady-state performance data are presented in Table VIII. The data presented were for a 1-sec data average of test measurements from 29 to 30 sec, and were computed using the Rocketdyne PAST 640 modification zero performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV.

4.2.2 Firing J4-1801-06B

Firing 06B was conducted 19 min after firing 06A to provide engine component temperatures after a simulated 90-min orbit; this firing was of 5-sec duration preceded by an 8-sec fuel lead. The propellant utilization valve was fully open throughout the firing. A summary of engine start requirements and results is presented in Table VI.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 13. The initial gas generator outlet temperature peak was 2160°F with a second peak of the same magnitude. Initial main oxidizer valve second stage movement occurred at t_o + 1.160 sec. Thrust chamber ignition occurred 0.942 sec after t_o, and no engine vibration (VSC) was recorded.

Transient fuel pump head/flow data for firing 06B was documented, and compared with the stall inception curve in Fig. 14. In the particular region of investigation for this firing (below approximately 550 gpm), a minimum stall margin of 600 gpm was realized.

A summary of start and shutdown times for engine valves during firing 06B is shown in Table VII. All valve operating times were consistent and normal.

Engine chamber pressure and test capsule ambient pressure for firing 06B are shown in Fig. 15. Thermal conditions of selected engine components are shown in Fig. 16.

4.2.3 Firing J4-1801-06C

Firing 06C was of 30-sec duration with a propellant utilization valve excursion from null to fully closed at t_o + 23 sec. The firing was preceded by a 3-sec fuel lead. A summary of engine start requirements and test results is presented in Table VI.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 17. The initial gas generator outlet temperature peak was 1400°F. Initial main oxidizer valve second stage movement occurred at t_o + 1.038 sec. Thrust chamber ignition occurred 1.035 sec after t_o, and engine vibrations (VSC) were recorded at t_o + 1.032 sec for 95 msec.

A summary of start and shutdown times for engine valves during firing 06C is shown in Table VII. All valve operating times were consistent and normal.

Engine chamber pressure and test capsule ambient pressure for firing 06C are shown in Fig. 18. The effects of the propellant utilization valve excursion occurred at approximately t_o + 23 sec, at which time engine chamber pressure increased from 690 to 780 psia. Thermal conditions of selected engine components are shown in Fig. 19.

Engine steady-state performance data are presented in Table VIII. The data presented were for a 1-sec data average of test measurements from 29 to 30 sec, and were computed using the Rocketdyne PAST 640 modification zero performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV.

4.2.4 Firing J4-1801-06D

The 90-min restart simulation firing, 06D, was of 5-sec duration preceded by an 8-sec fuel lead. The propellant utilization valve was fully open throughout the firing. A summary of engine start requirements and results is presented in Table VI.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 20. The initial gas generator outlet temperature peak was 1970°F. Initial main oxidizer valve second stage movement occurred at t_o + 1.016 sec. Thrust chamber ignition occurred 1.008 sec after t_o, and engine vibrations (VSC) were observed at t_o + 1.012 sec for 18 msec.

A summary of start and shutdown times for engine valves during firing 06D is shown in Table VII. All valve operating times were consistent and normal.

Engine chamber pressure and test capsule ambient pressure for firing 06D are shown in Fig. 21.

Thermal conditions of selected engine components are shown in Fig. 22. The cool-down rate of the turbine crossover system, prior to this firing, was excessive, indicating possible leakage through the gas generator control valve. A pressure decay check of the fuel system, immediately following the firing, indicated leakage; however, subsequent leak checks conducted at ambient temperature conditions did not locate a leakage source.

4.2.5 Post-Test Inspection

Post-test inspection showed the engine condition to be satisfactory.

SECTION V
SUMMARY OF RESULTS

The results of these four firings of the Rocketdyne J-2 engine conducted on August 22, 1967, in Test Cell J-4 are summarized as follows:

1. A minimum fuel pump stall margin of 600 gpm was realized in the flow region above 5500 gpm for a first-burn simulation with low starting energy.
2. A minimum fuel pump stall margin of 1600 gpm was realized in the flow region below 5500 gpm for a restart simulation with high starting energy.
3. Thrust chamber ignition characteristics for a first burn with low augmented spark igniter mixture ratio were satisfactory.
4. Engine vibrations in excess of ±150 g in the frequency range of 960 to 6000 Hz were measured during three of the four firings.
5. Engine valve operating times were consistent and normal.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. "U.S. Standard Atmosphere, 1962." December 1962.

2. Counts, H. J. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-05)." AEDC-TR-67-208 (AD821828), October, 1967.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook, (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

PRECEDING PAGE BLANK-NOT FILMED

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATION
(PERFORMANCE PROGRAM)

Fig. 1 Test Cell J-4 Complex

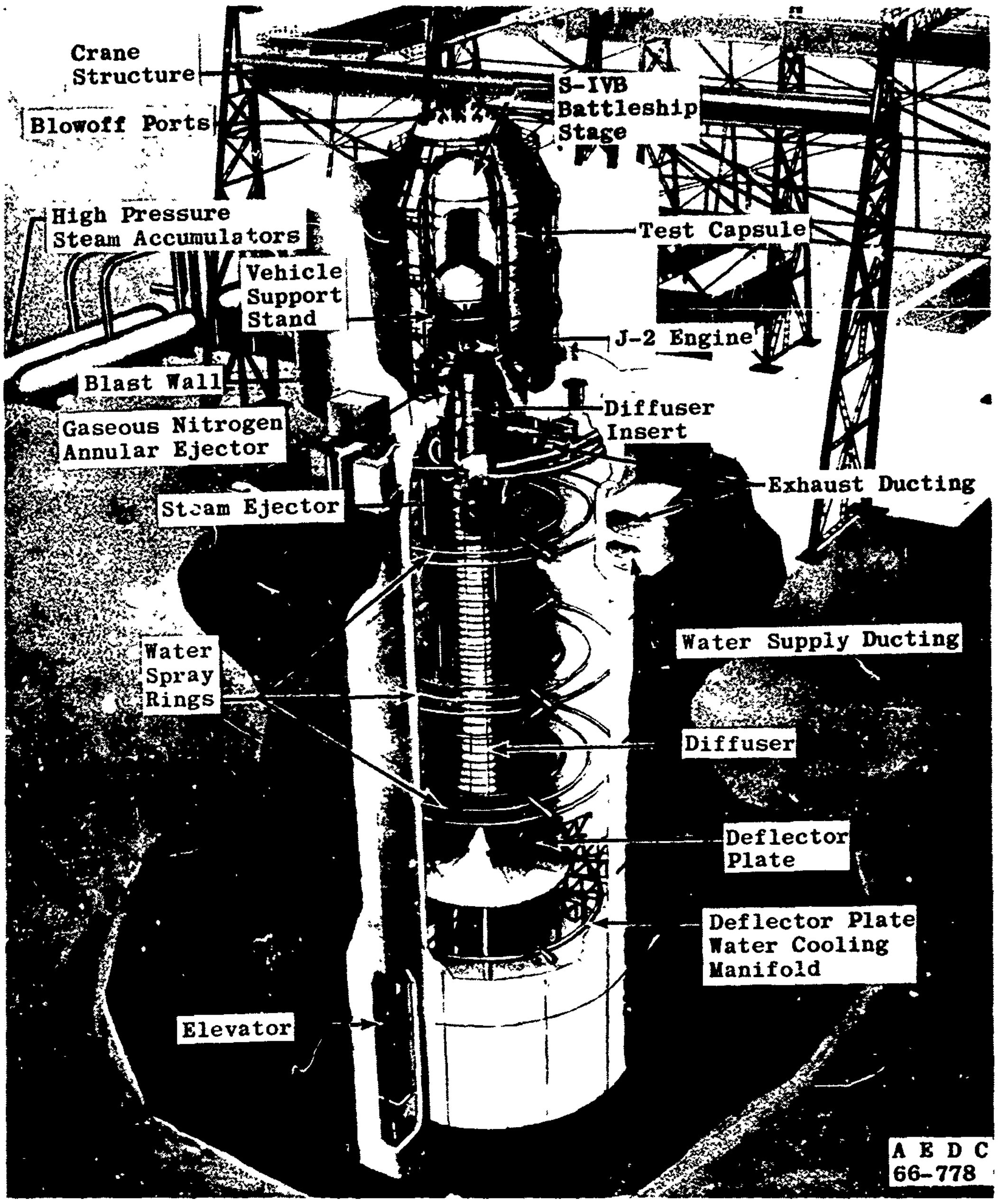


Fig. 2 Test Cell J-4 Artist's Conception

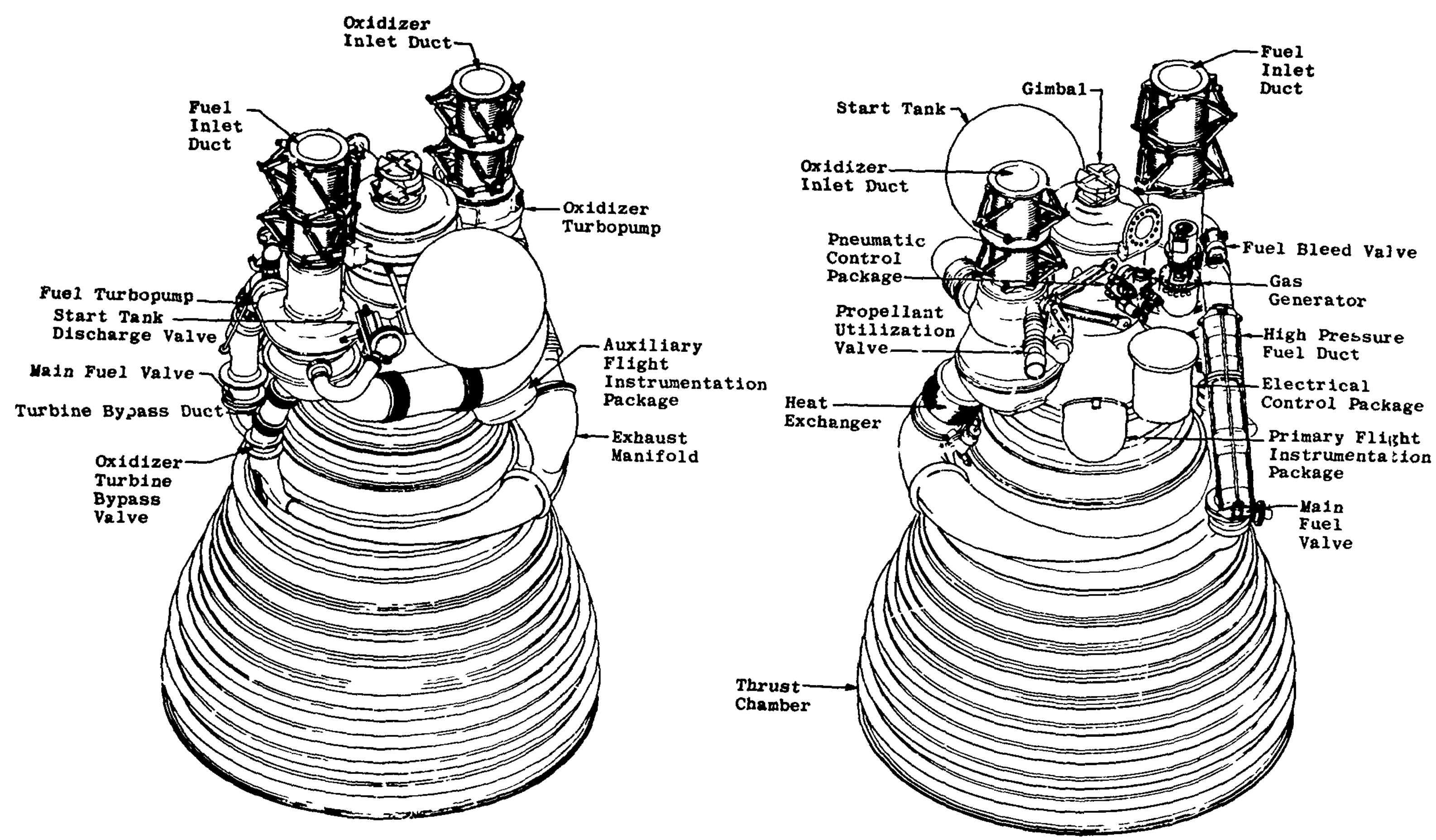


Fig. 3 Details

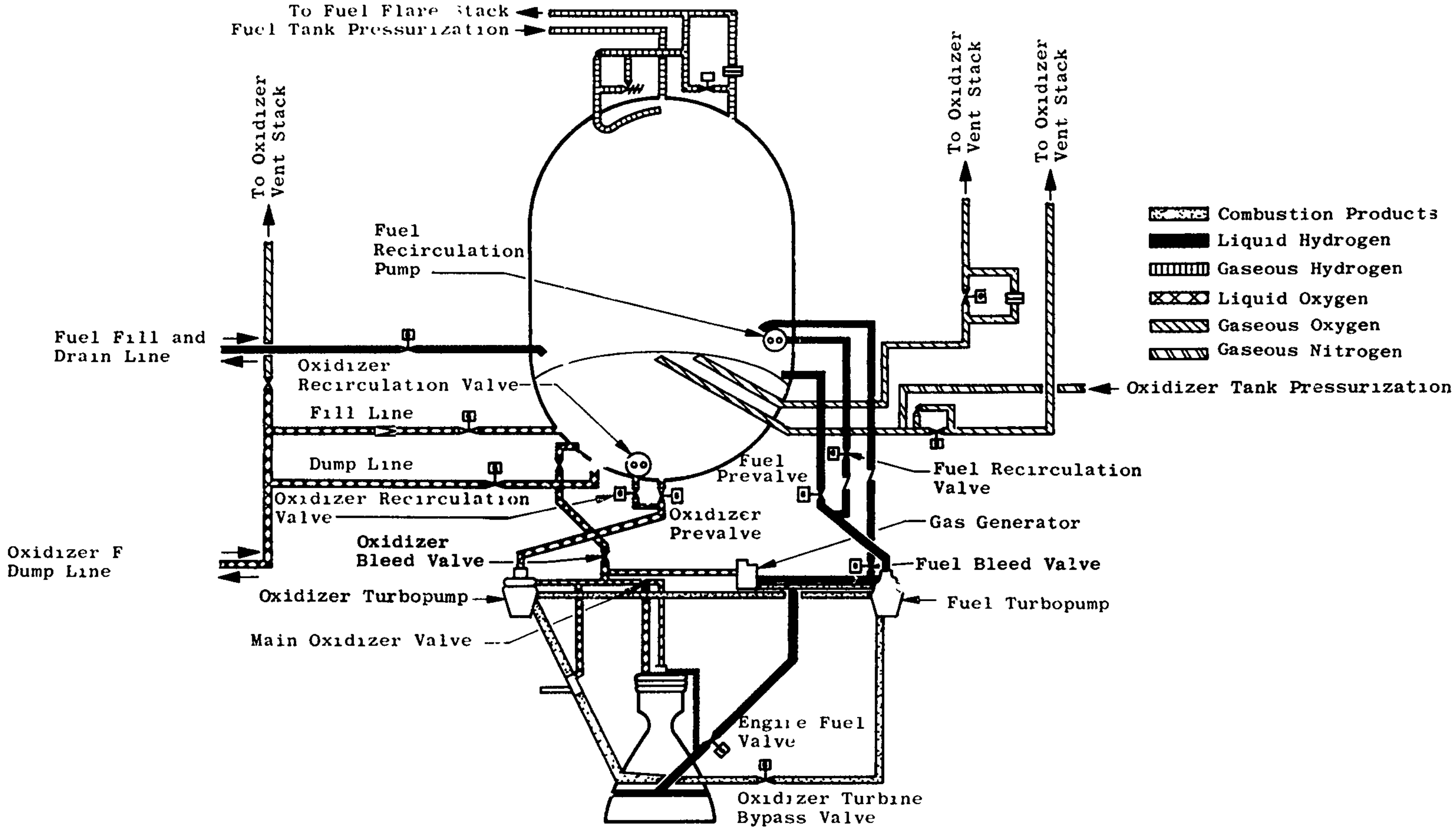
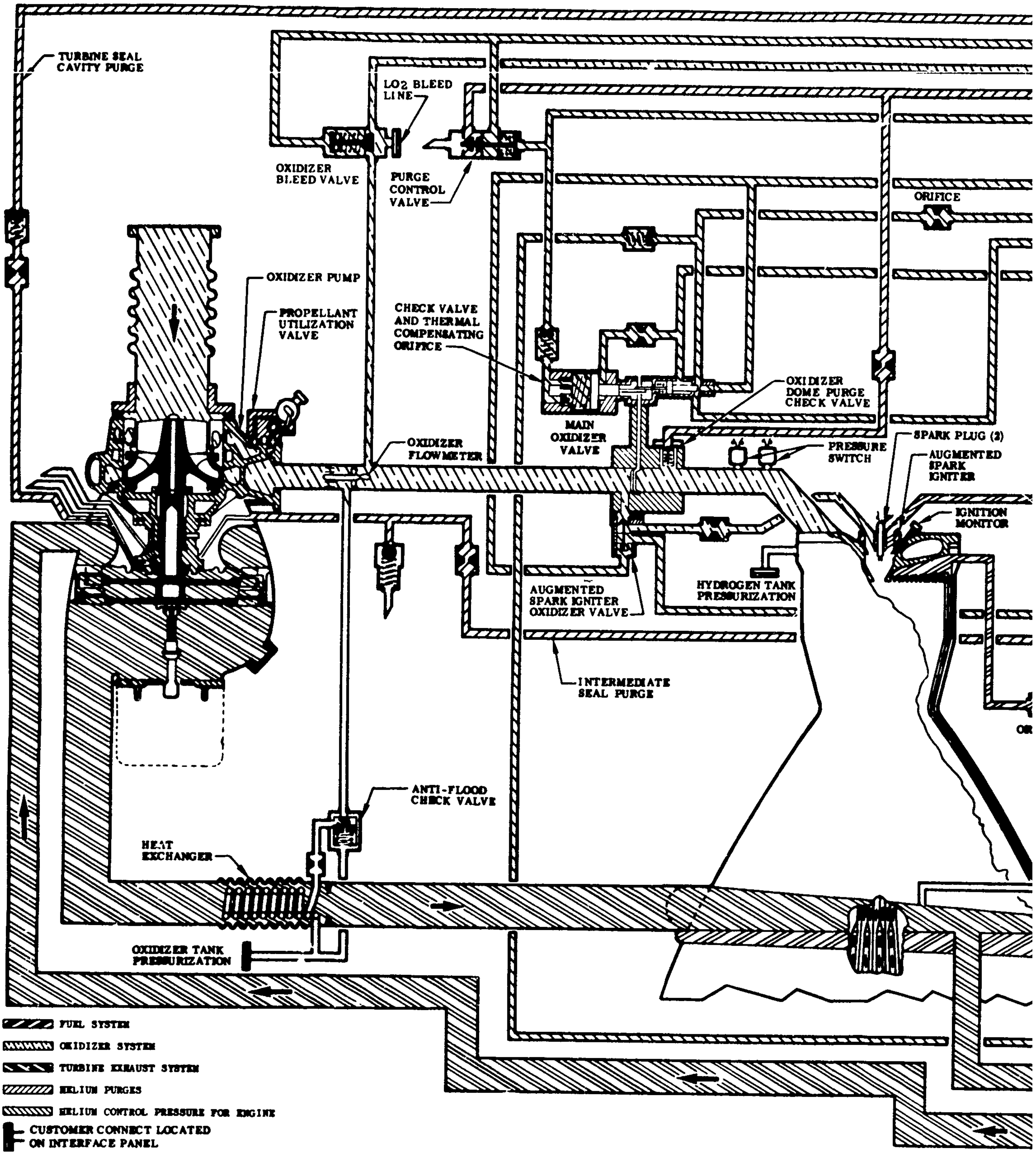


Fig. 4 S-IVB Battleship Stage/J-4 Engine Schematic


TURBINE SEAL CAVITY PURGE
LO2 BLEED LINE
OXIDIZER BLEED VALVE
PURGE CONTROL VALVE
ORIFICE
OXIDIZER PUMP
PROPELLANT UTILIZATION VALVE
CHECK VALVE AND THERMAL COMPENSATING ORIFICE
OXIDIZER DOME PURGE CHECK VALVE
MAIN OXIDIZER VALVE
OXIDIZER FLOWMETER
PRESSURE SWITCH
SPARK PLUG (2)
AUGMENTED SPARK IGNITER
IGNITION MONITOR
AUGMENTED SPARK IGNITER OXIDIZER VALVE
HYDROGEN TANK PRESSURIZATION
INTERMEDIATE SEAL PURGE
ANTI-FLOOD CHECK VALVE
HEAT EXCHANGER
OXIDIZER TANK PRESSURIZATION
FUEL SYSTEM
OXIDIZER SYSTEM
TURBINE EXHAUST SYSTEM
HELIUM PURGES
HELIUM CONTROL PRESSURE FOR ENGINE
CUSTOMER CONNECT LOCATED ON INTERFACE PANEL

1

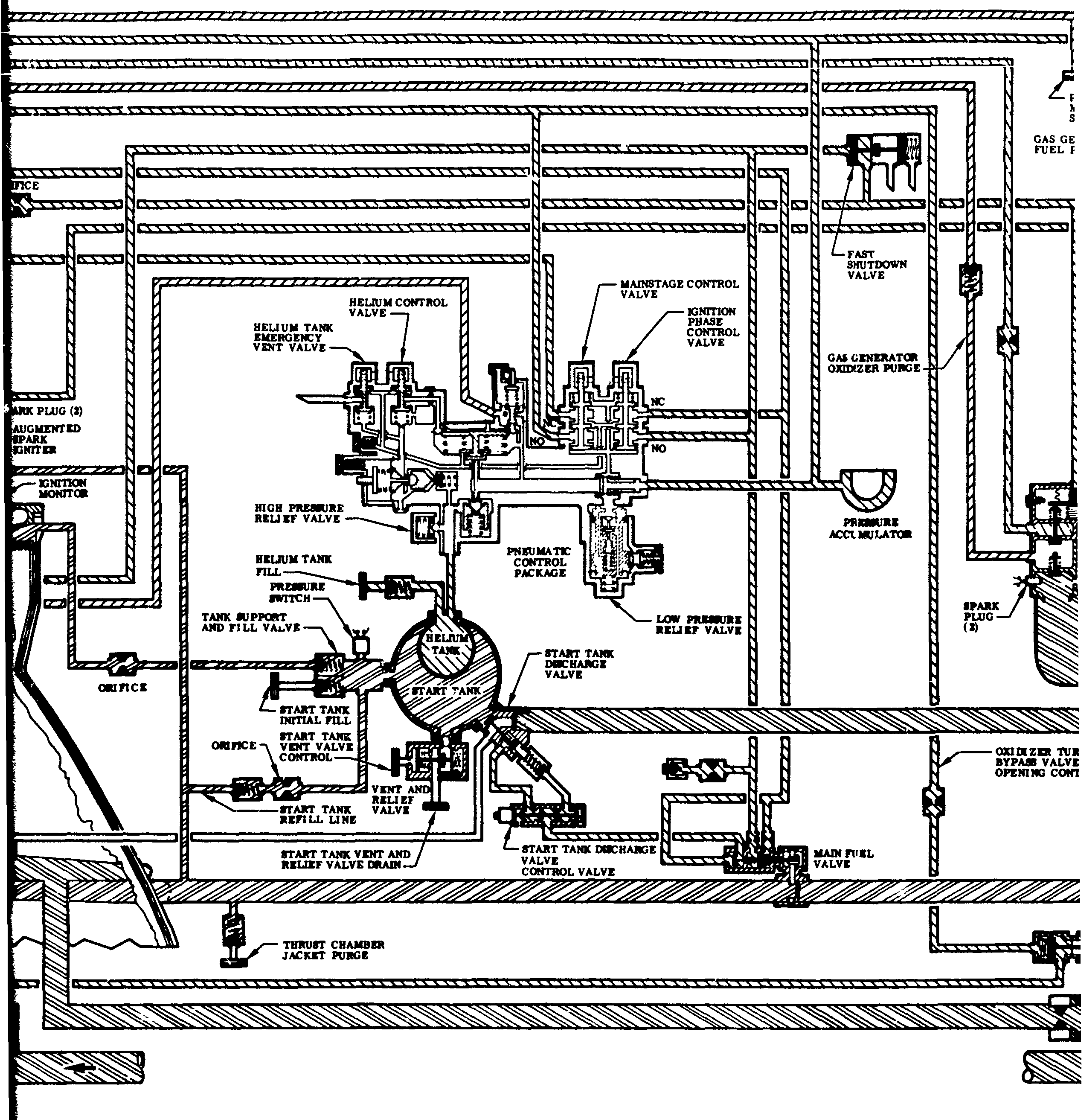
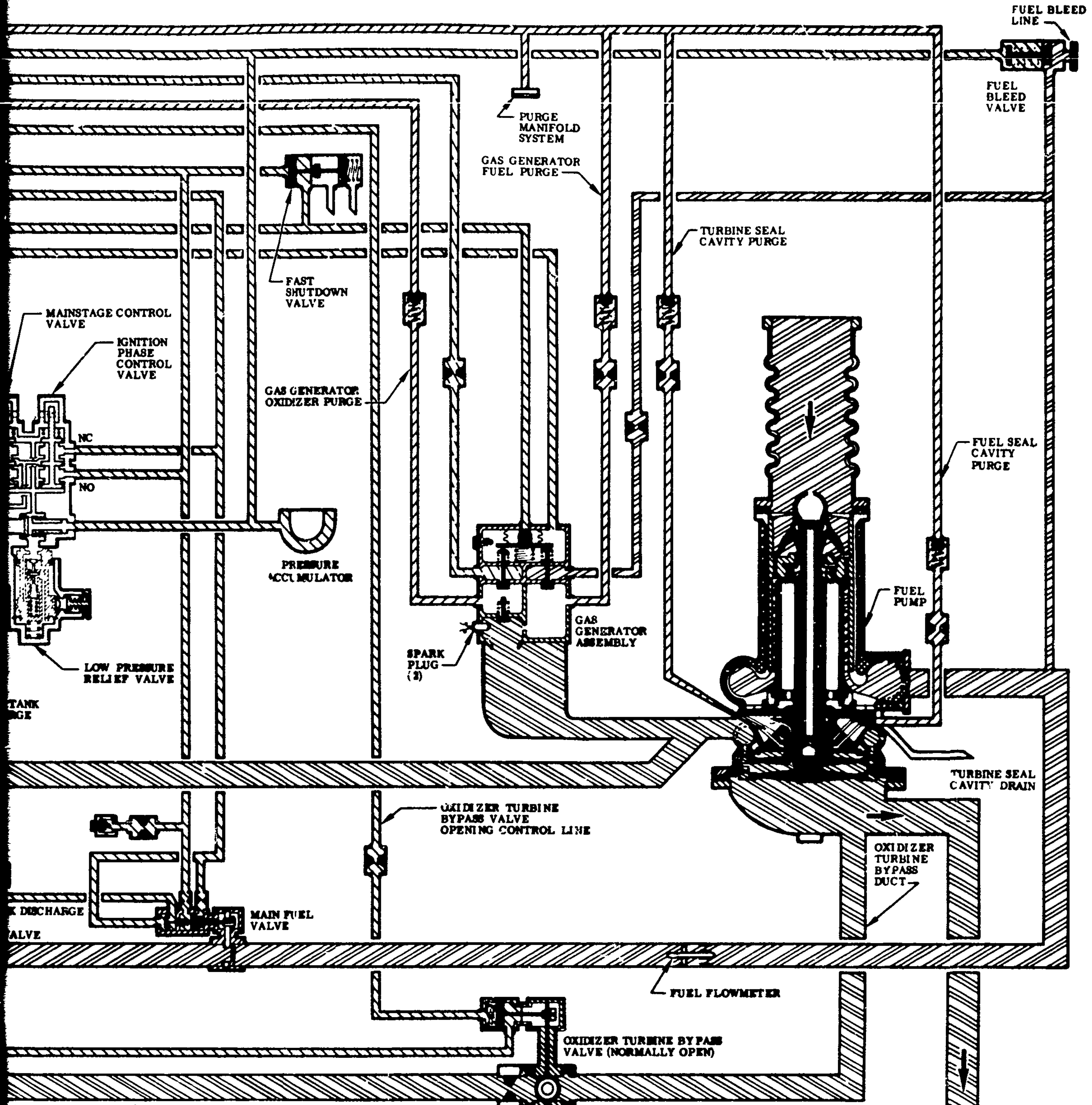
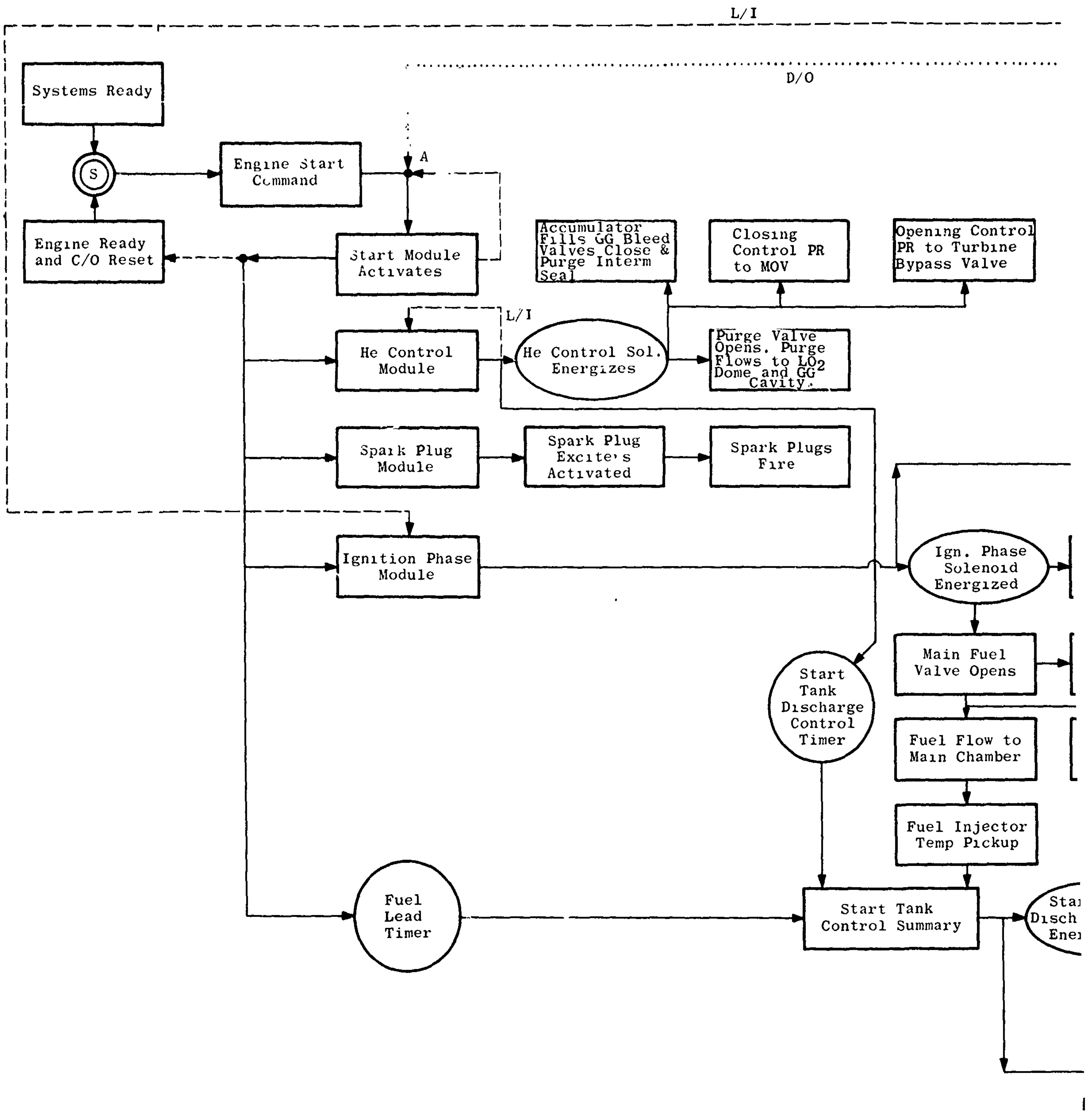


Fig. 5 Engine Schematic


FUEL BLEED LINE
FUEL BLEED VALVE
PURGE MANIFOLD SYSTEM
GAS GENERATOR FUEL PURGE
FAST SHUTDOWN VALVE
TURBINE SEAL CAVITY PURGE
MAINSTAGE CONTROL VALVE
IGNITION PHASE CONTROL VALVE
GAS GENERATOR OXIDIZER PURGE
NC
NO
FUEL SEAL CAVITY PURGE
PRESSURE ACCUMULATOR
FUEL PUMP
GAS GENERATOR ASSEMBLY
SPARK PLUG (2)
LOW PRESSURE RELIEF VALVE
TURBINE SEAL CAVITY DRAIN
OXIDIZER TURBINE BYPASS VALVE OPENING CONTROL LINE
OXIDIZER TURBINE BYPASS DUCT
MAIN FUEL VALVE
FUEL FLOWMETER
OXIDIZER TURBINE BYPASS VALVE (NORMALLY OPEN)

3

1


L/I
D/O
Systems Ready
S
Engine Start Command
A
Engine Ready and C/O Reset
Start Module Activates
Accumulator Fills GG Bleed Valves Close & Purge Interm Seal
Closing Control PR to MOV
Opening Control PR to Turbine Bypass Valve
L/I
He Control Module
He Control Sol. Energizes
Purge Valve Opens. Purge Flows to LO2 Dome and GG Cavity.
Spark Plug Module
Spark Plug Exciters Activated
Spark Plugs Fire
Ignition Phase Module
Ign. Phase Solenoid Energized
Main Fuel Valve Opens
Start Tank Discharge Control Timer
Fuel Flow to Main Chamber
Fuel Injector Temp Pickup
Fuel Lead Timer
Start Tank Control Summary

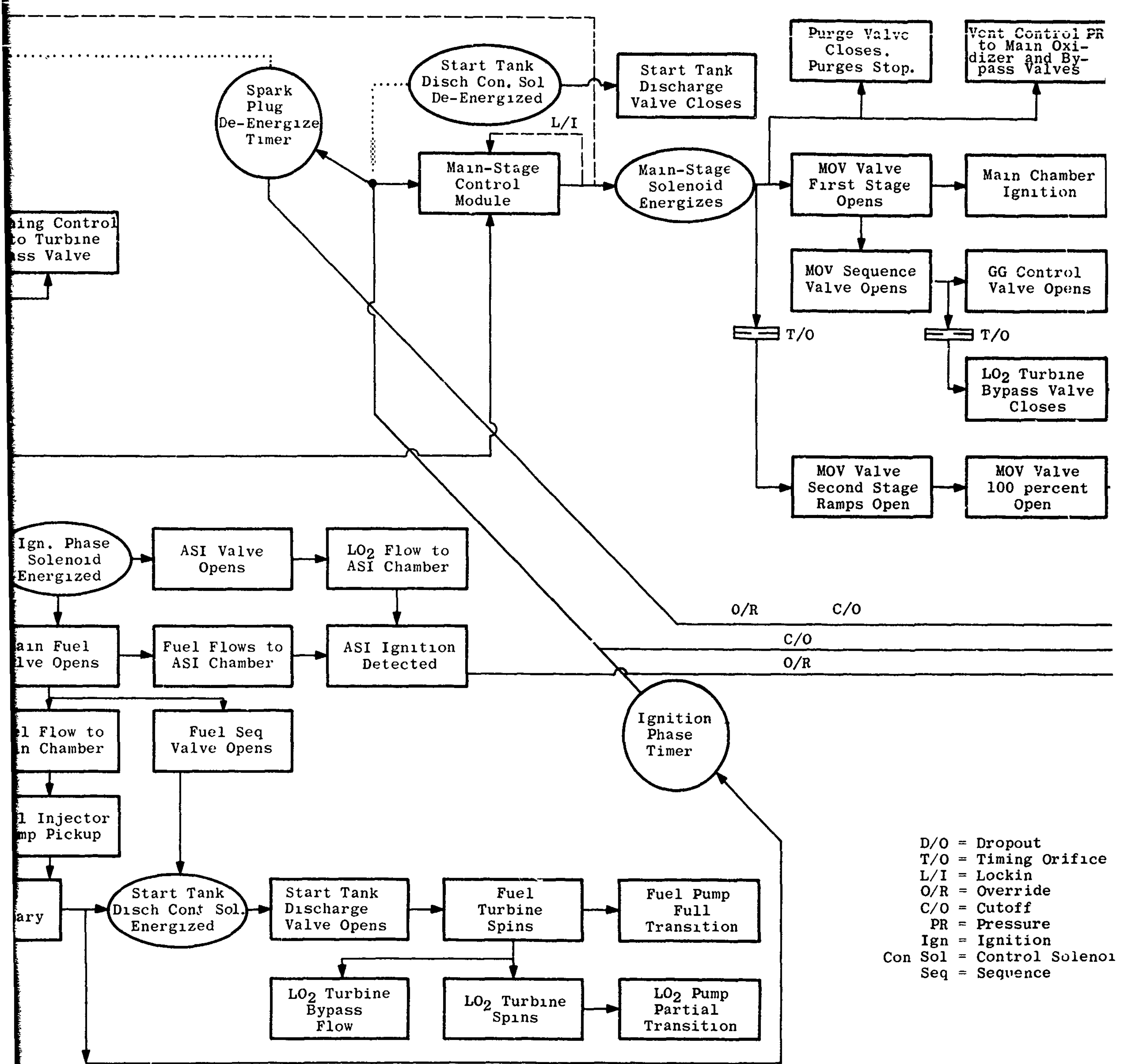
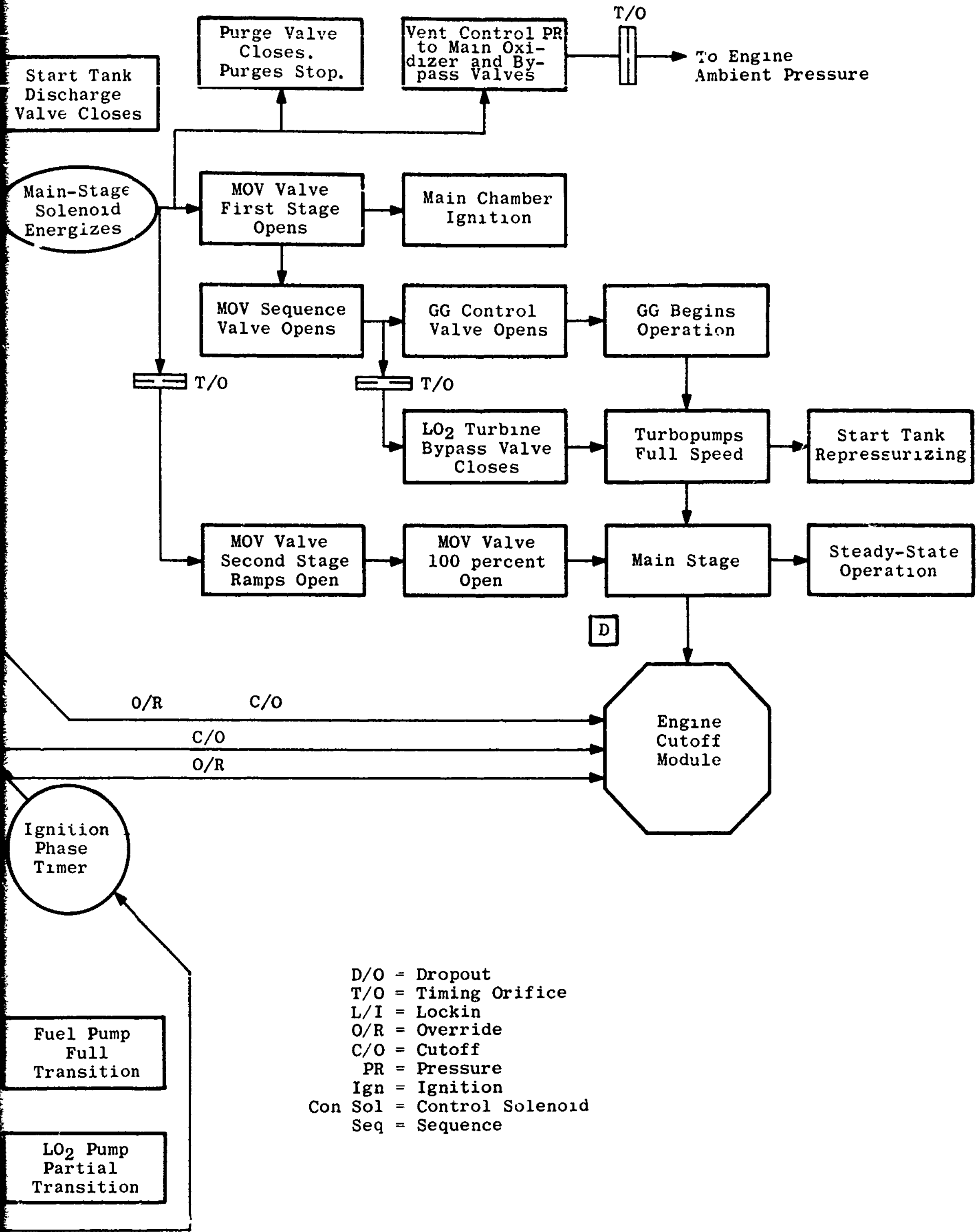
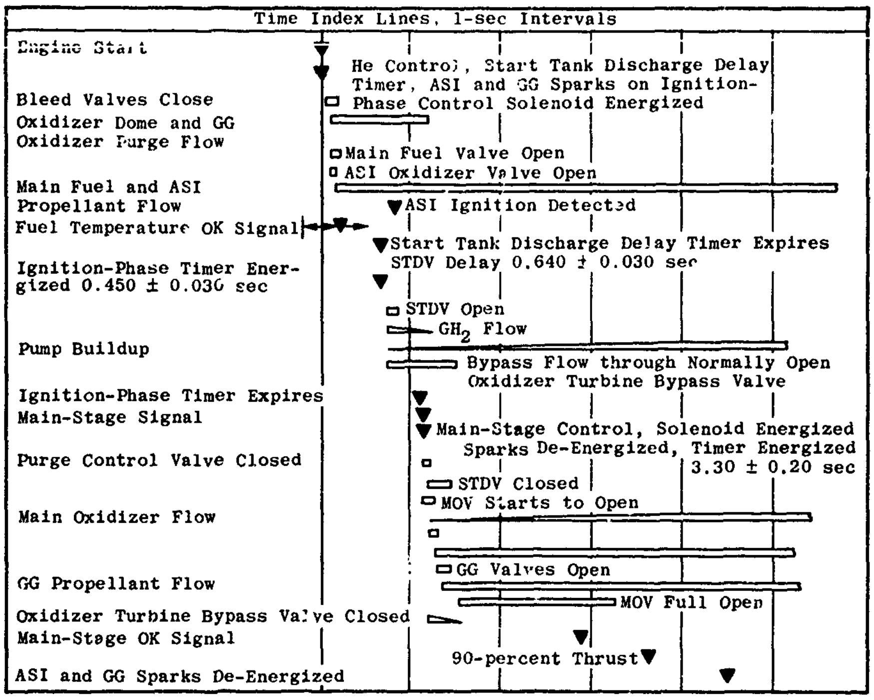


Fig. 6 Engine Start Logic Schematic

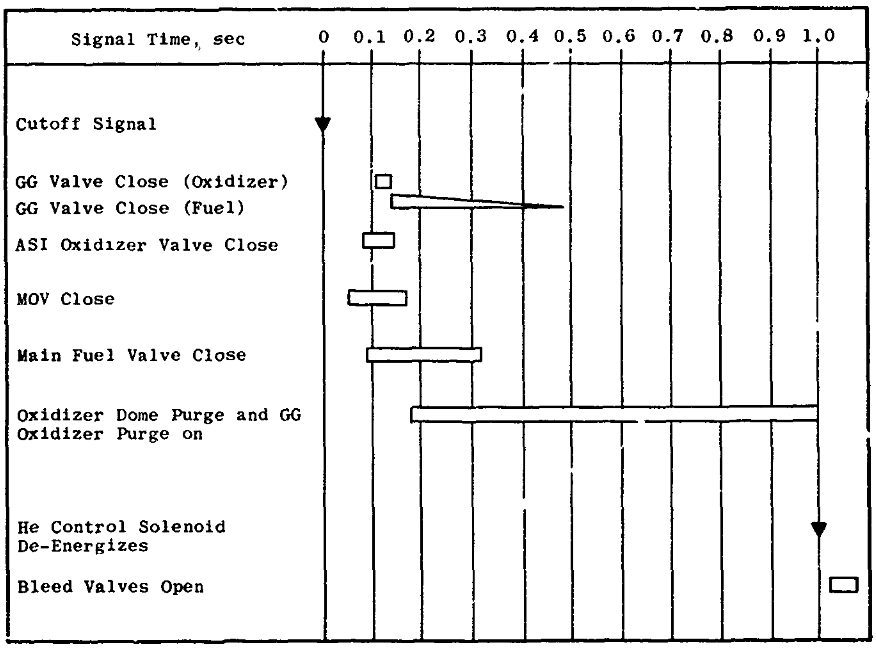
3



D/O = Dropout
T/O = Timing Orifice
L/I = Lockin
O/R = Override
C/O = Cutoff
PR = Pressure
Ign = Ignition
Con Sol = Control Solenoid
Seq = Sequence

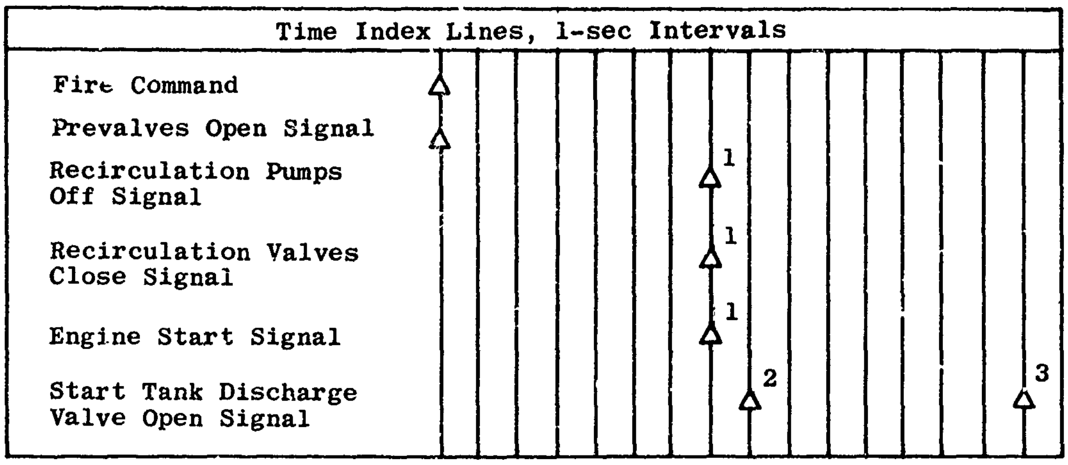


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Start and Shutdown Sequence

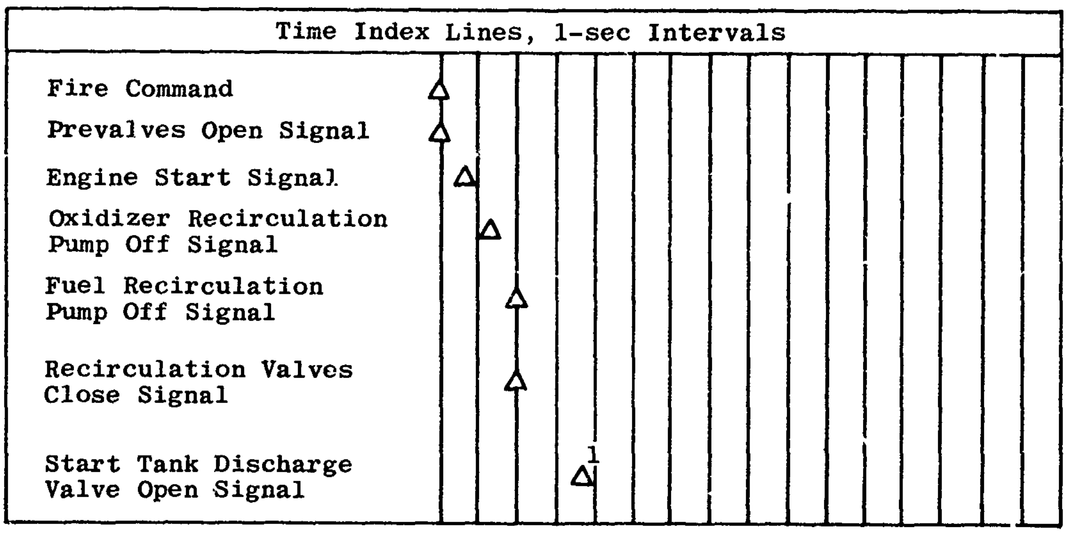


[1] Nominal Occurrence Time (Function of Prevalves Opening Time)

[2] One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

[3] Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

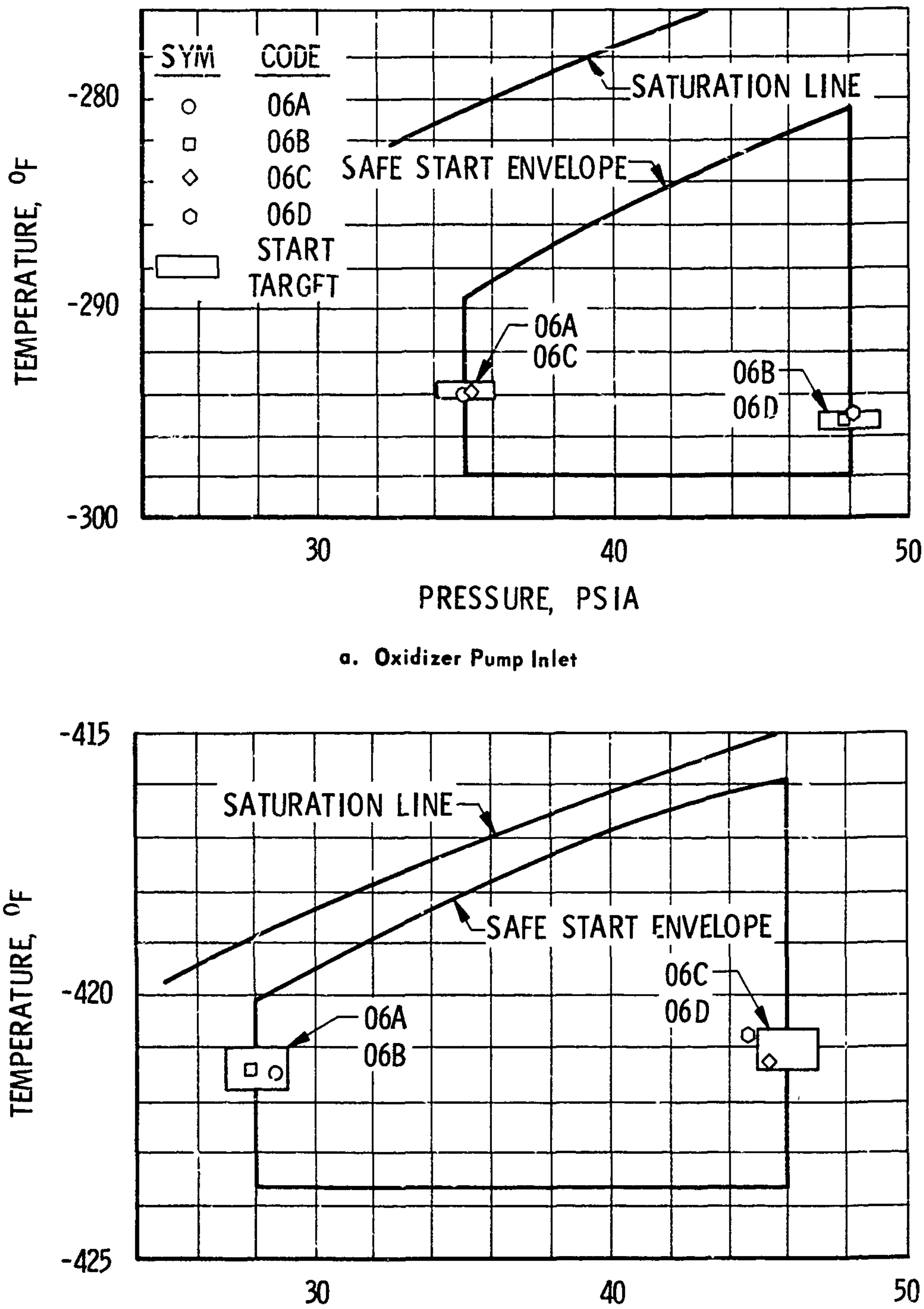
c. Normal Logic Start Sequence



[1] Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

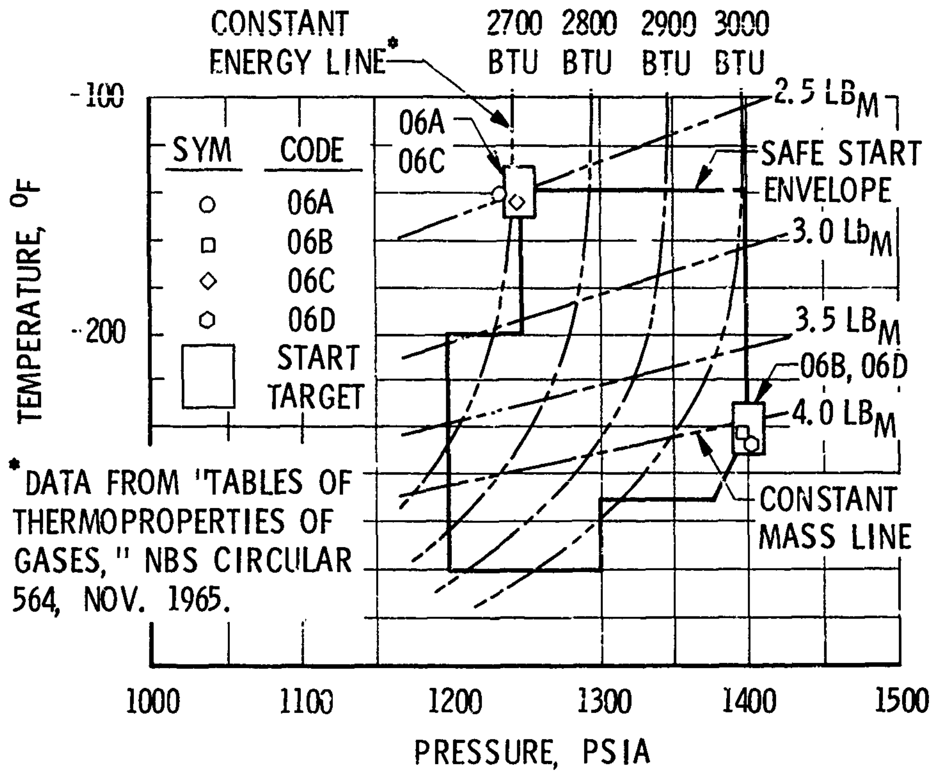
Fig. 7 Concluded



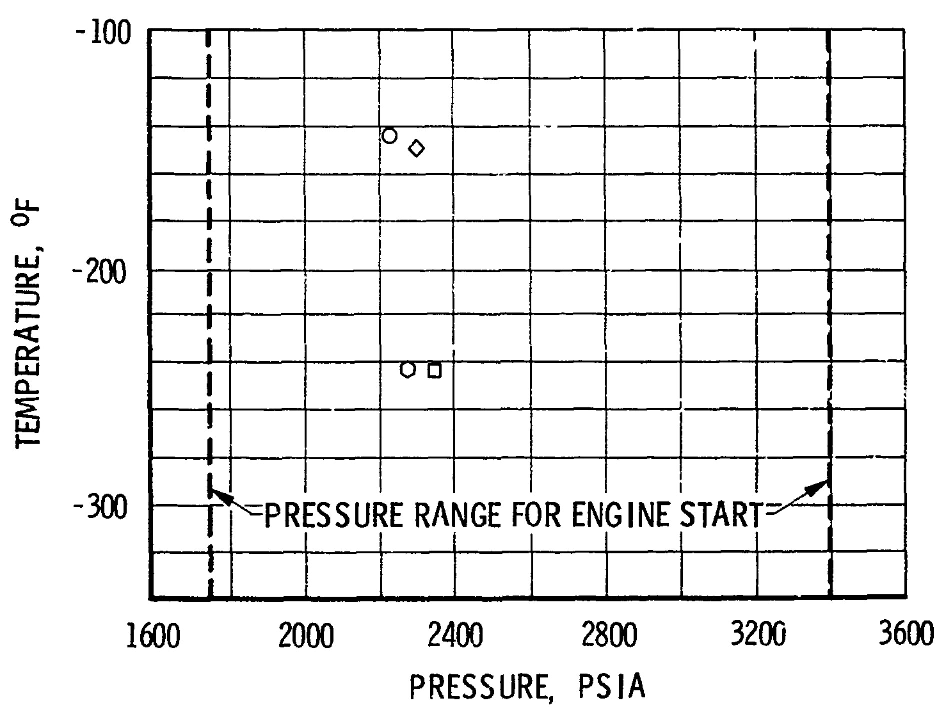
a. Oxidizer Pump Inlet

b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

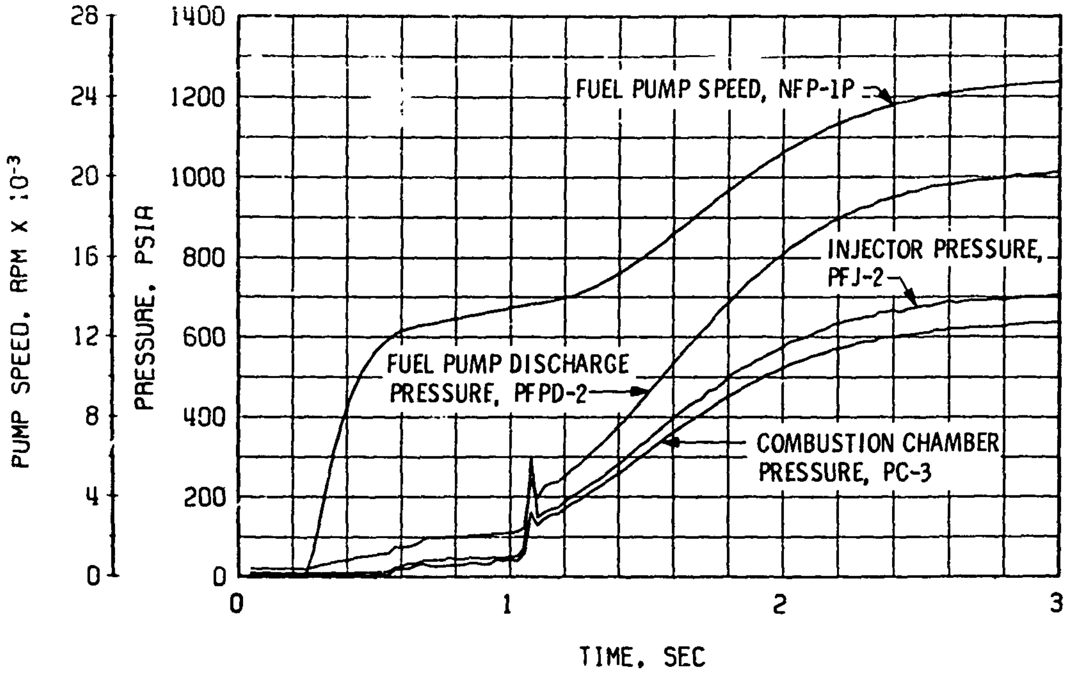


c. Start Tank

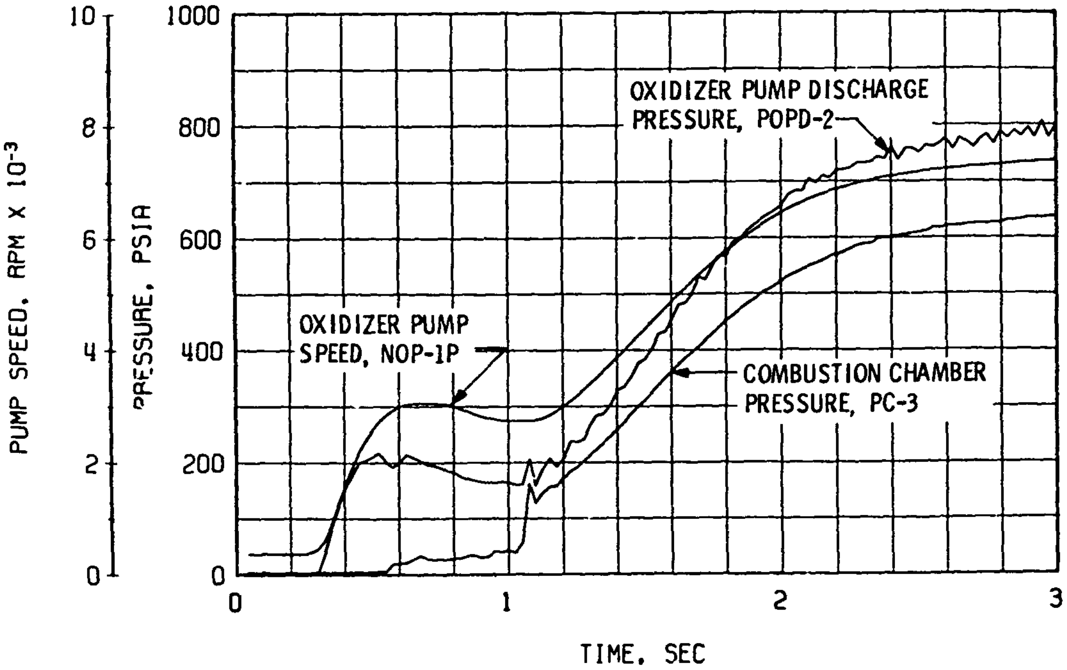


d. Helium Tank

Fig. 8 Concluded

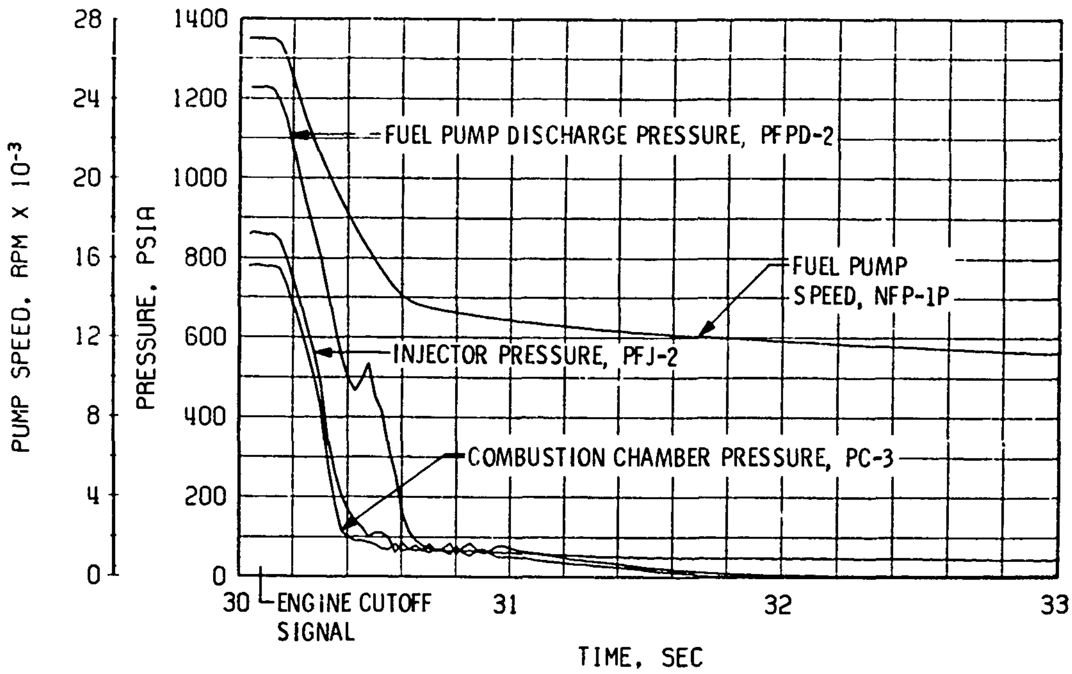


a. Thrust Chamber Fuel System, Start

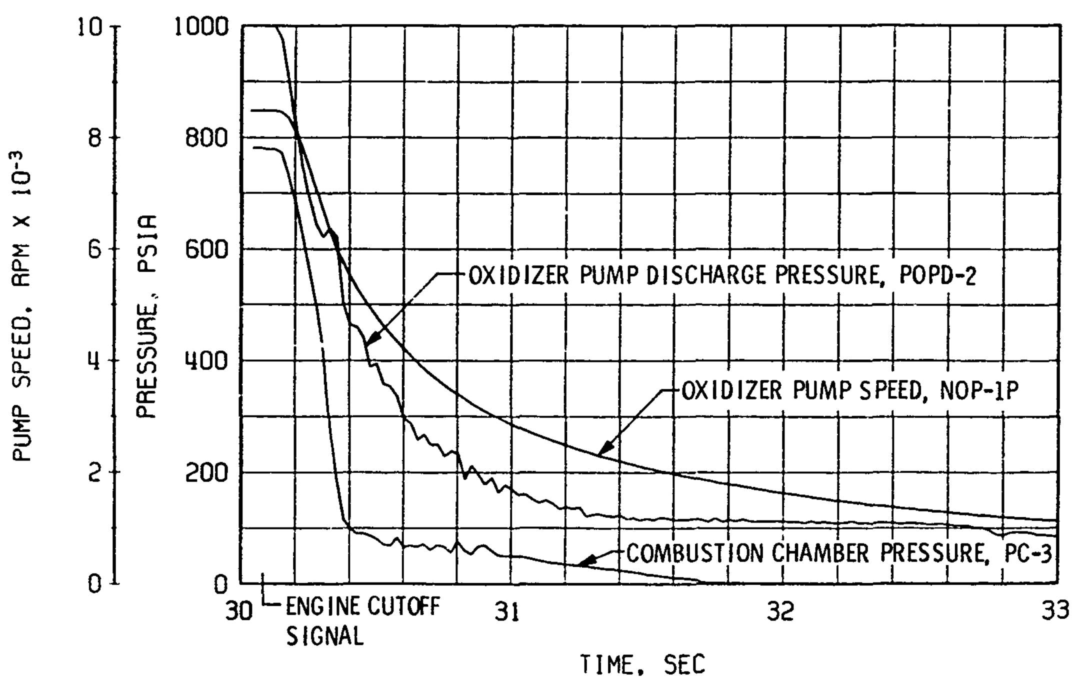


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 06A

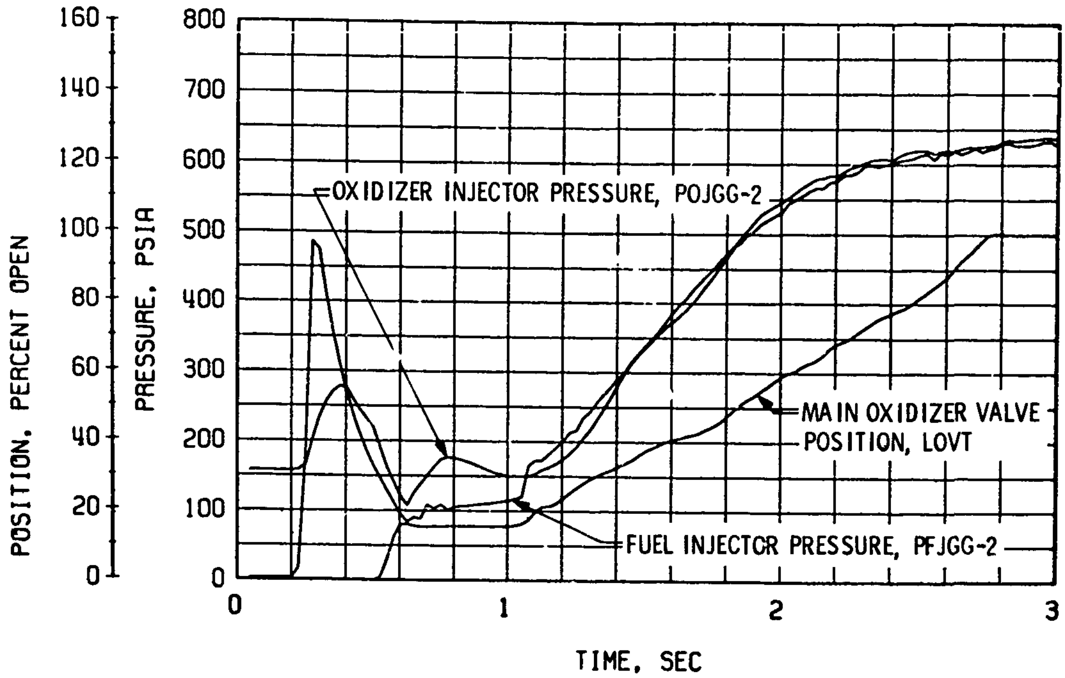


c. Thrust Chamber Fuel System, Shutdown

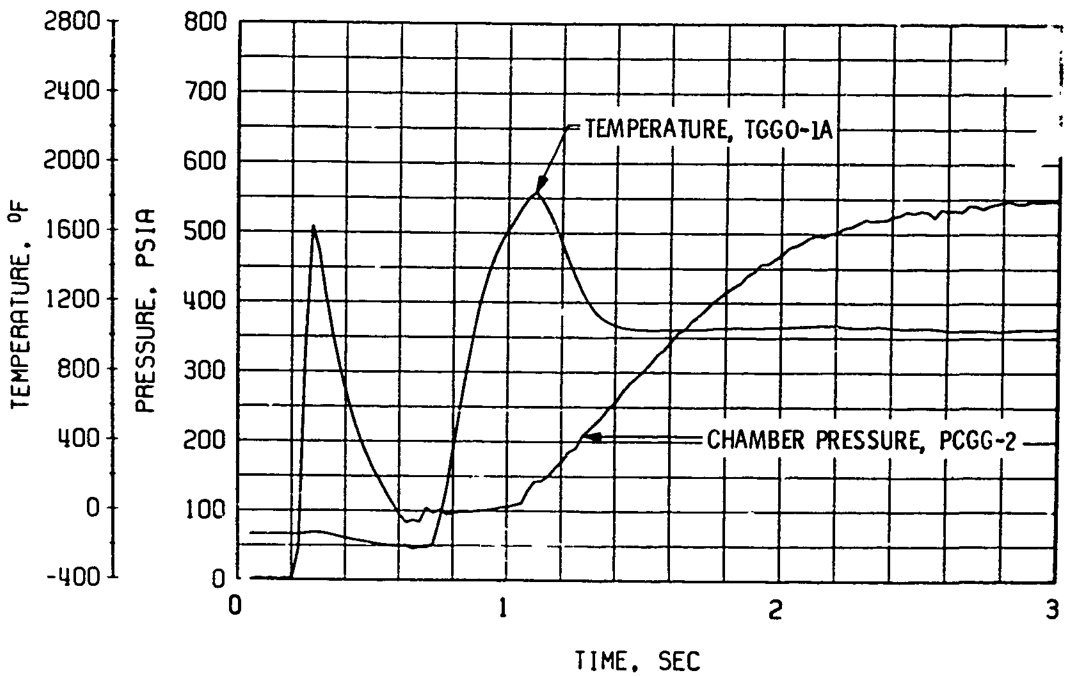


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued

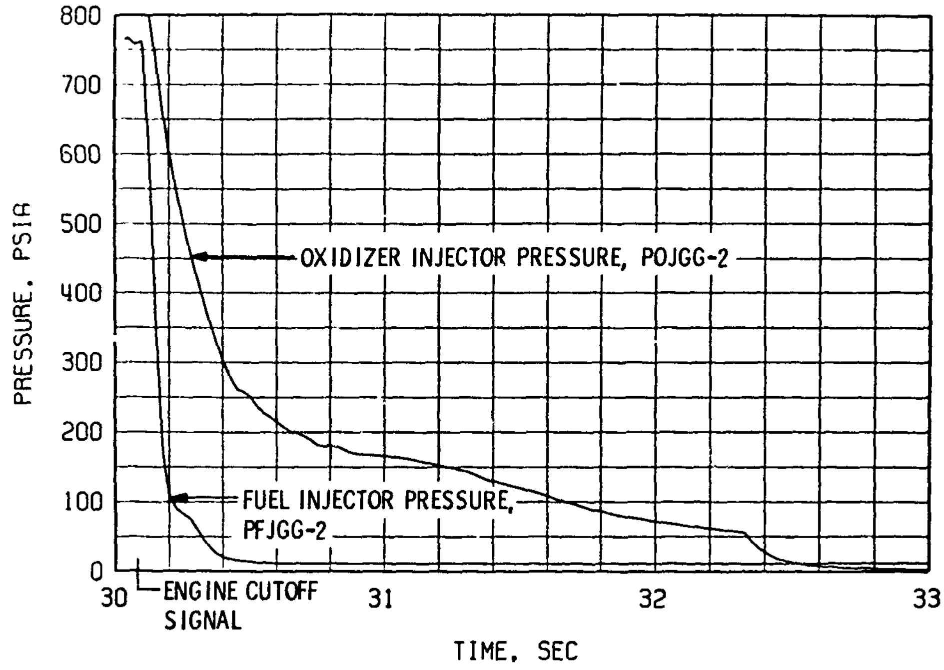


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

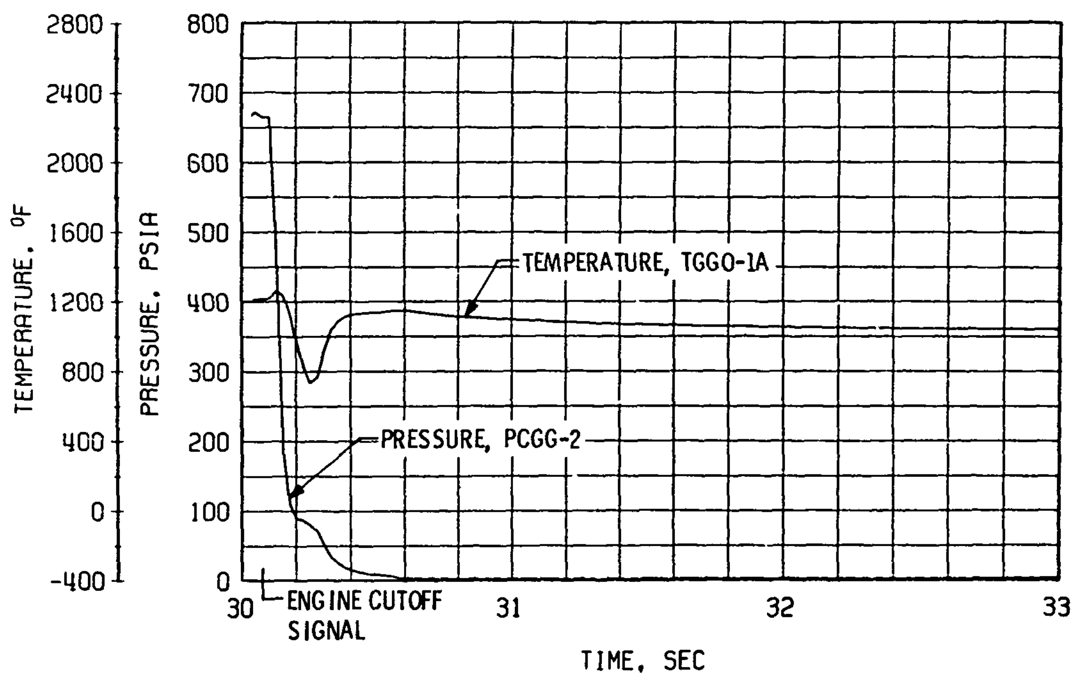


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 9 Concluded

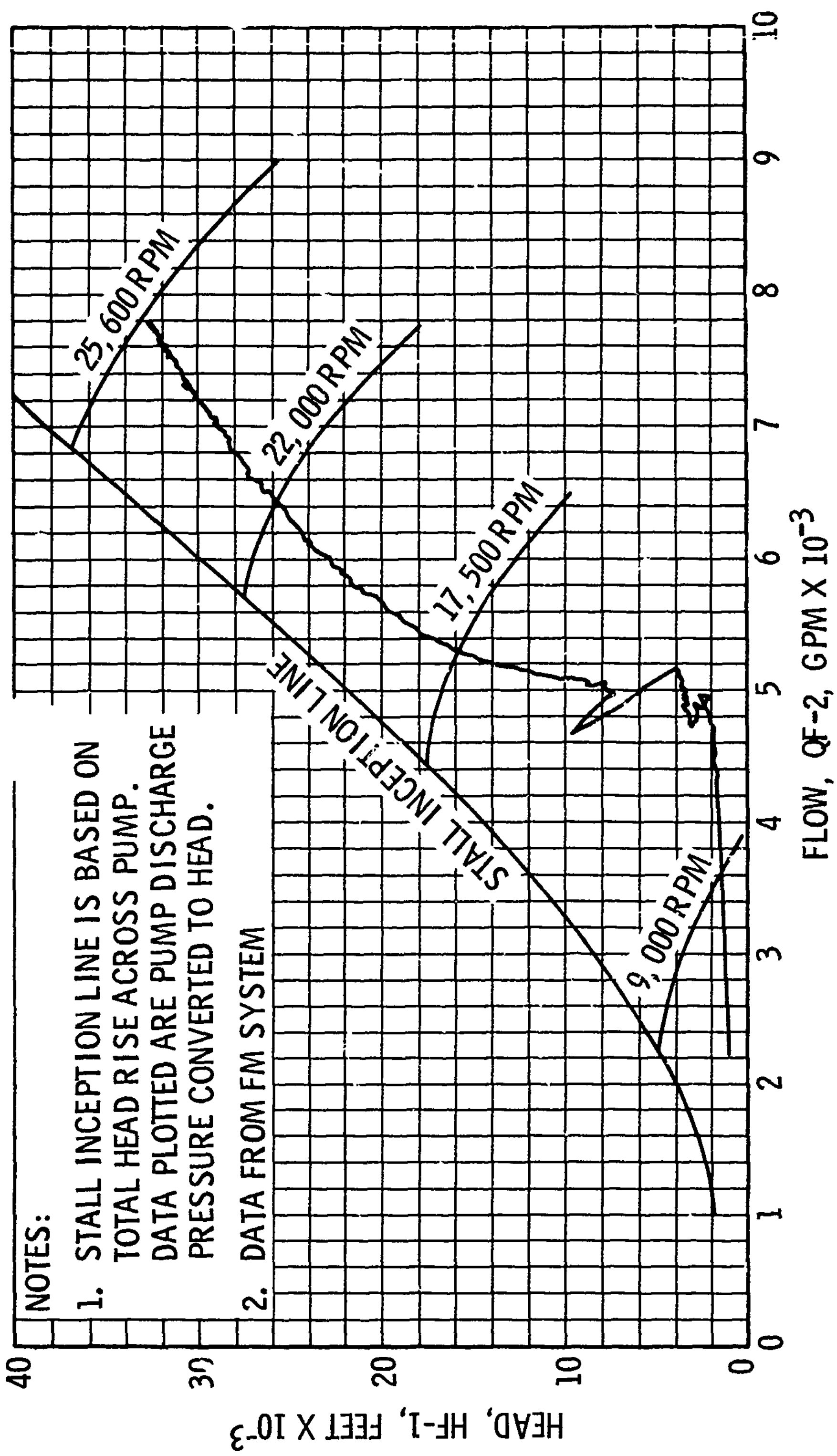


Fig. 10 Fuel Pump Start Transient Performance, Firing 06A

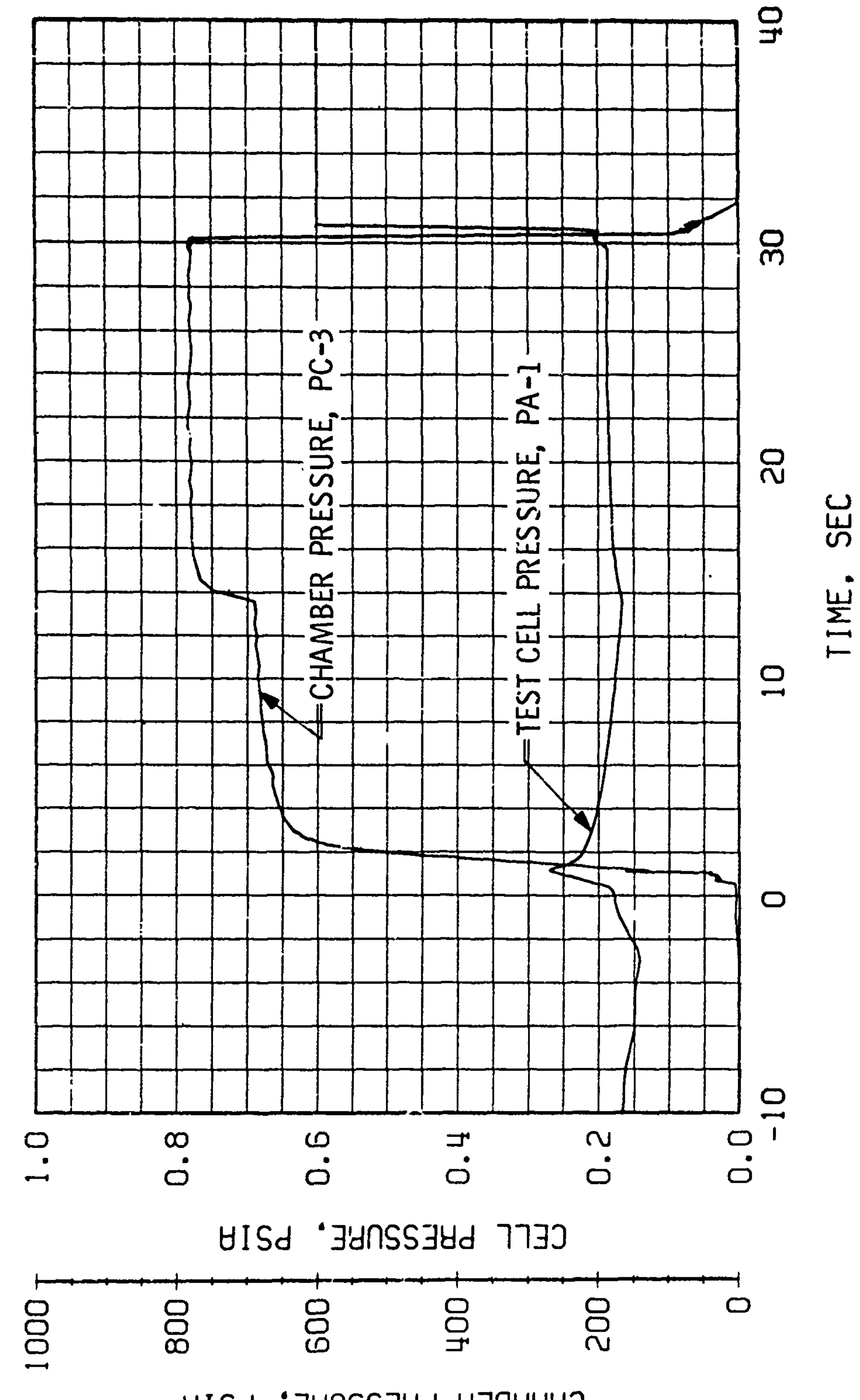
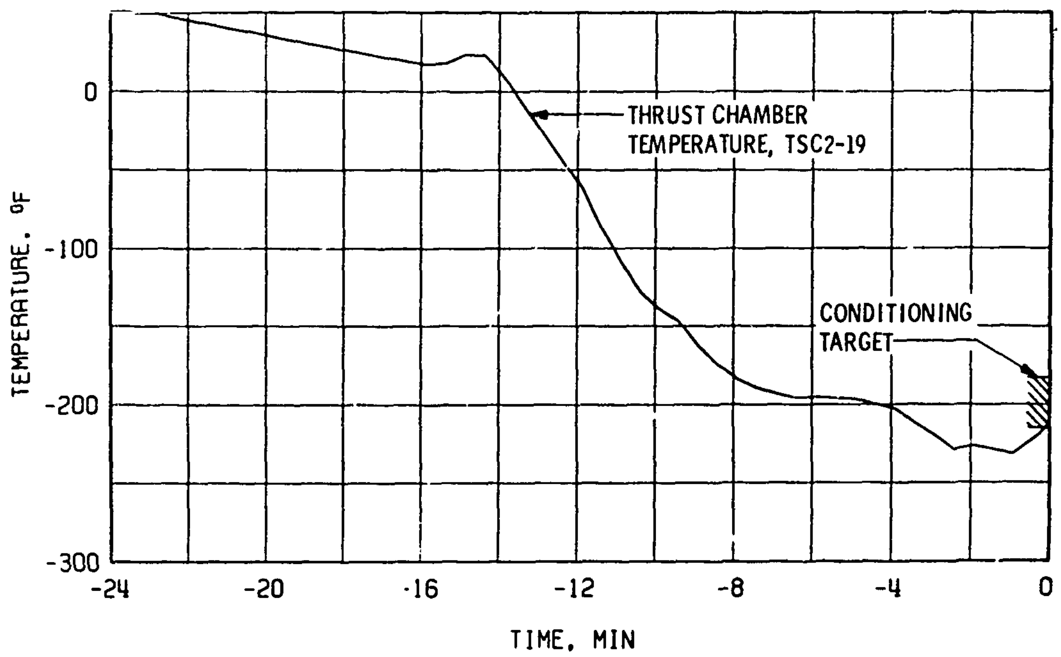
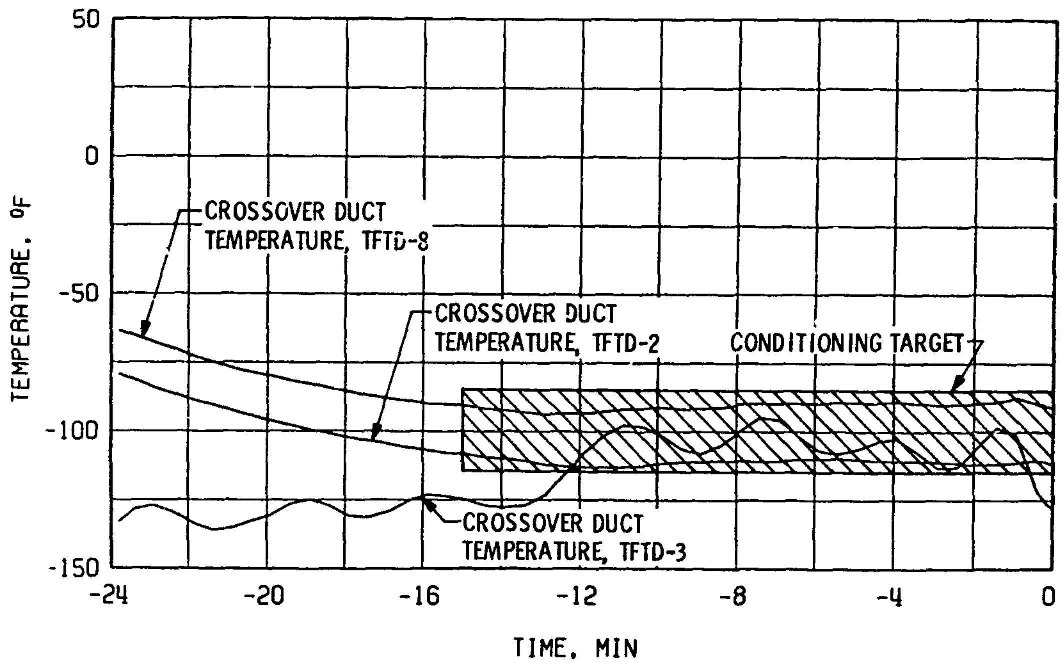


Fig. 11 Engine Ambient and Combustion Chamber Pressures, Firing 06A

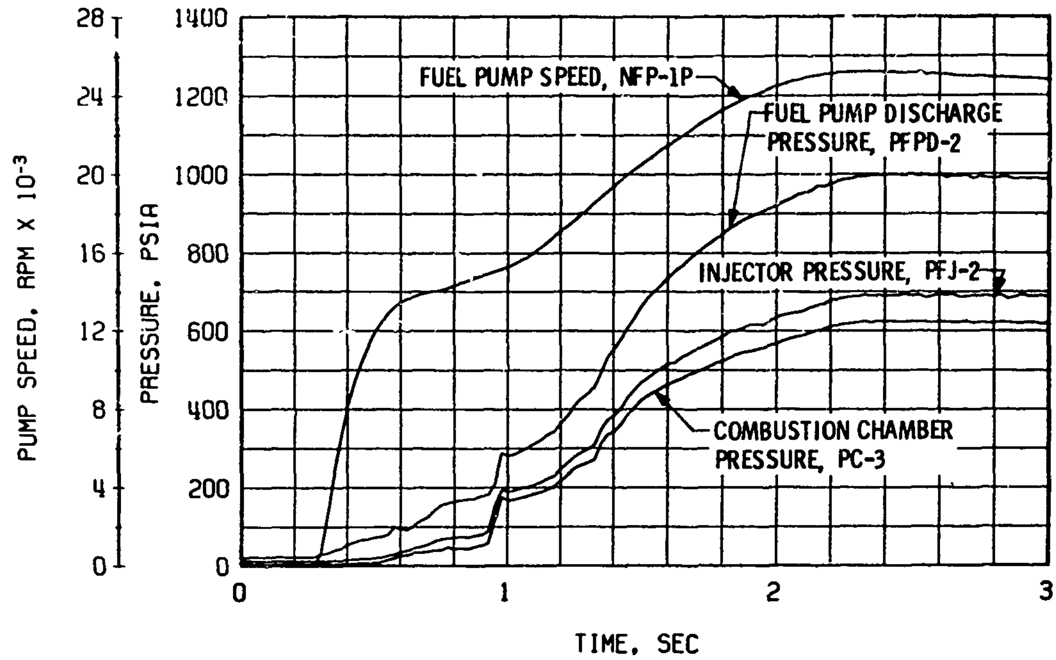


a. Thrust Chamber

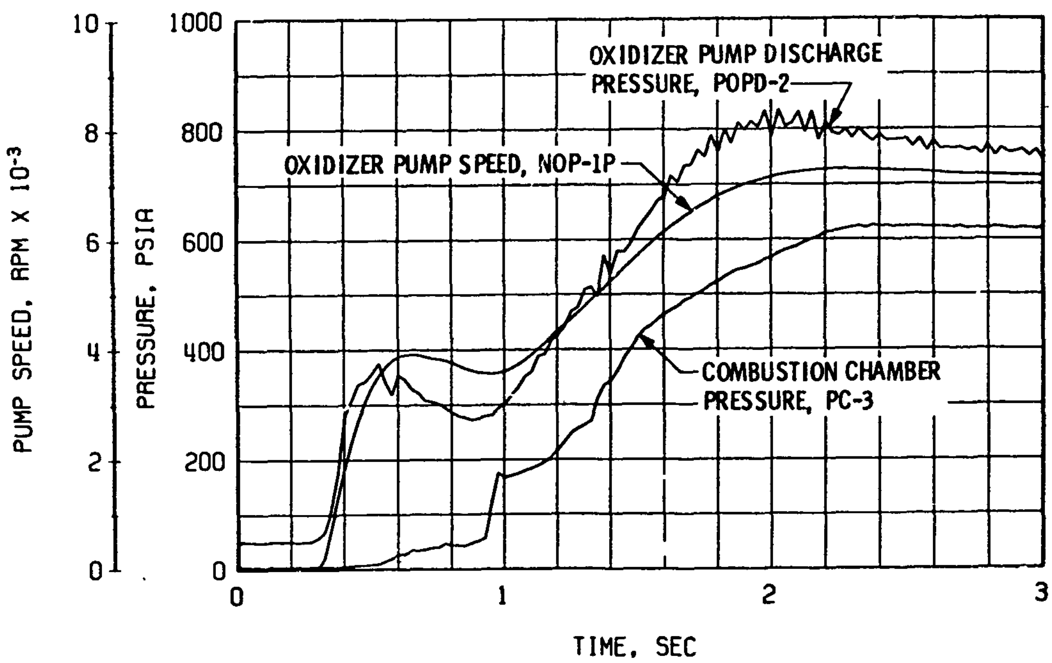


b. Turbines and Crossover Duct

Fig. 12 Thermal Conditioning History of Engine Components, Prefire 06A

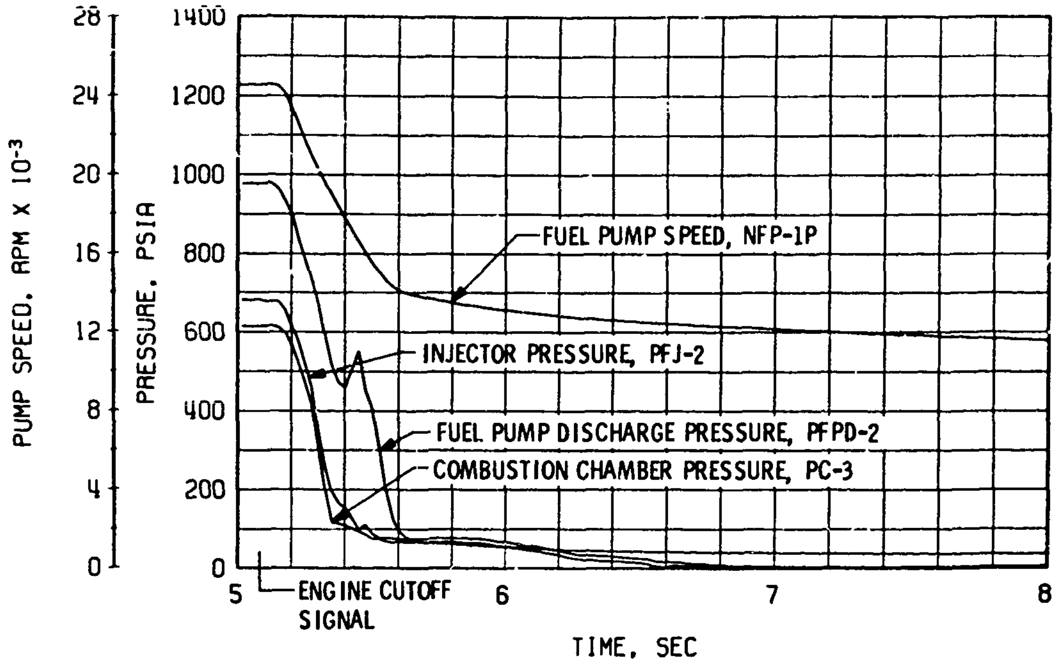


a. Thrust Chamber Fuel System, Start

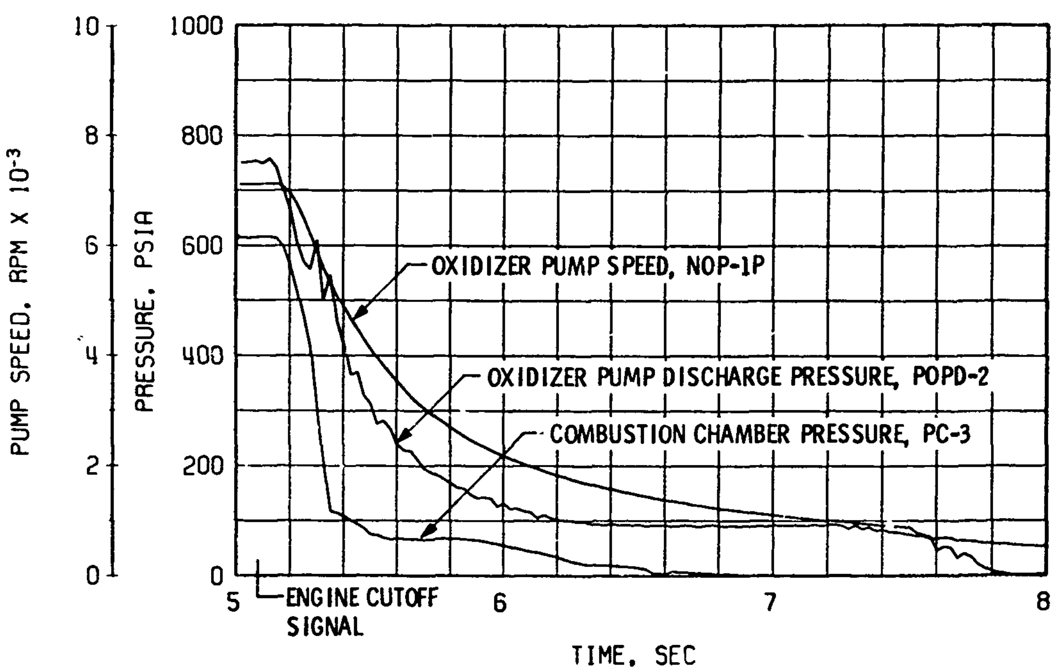


b. Thrust Chamber Oxidizer System, Start

Fig. 13 Engine Transient Operation, Firing 06B

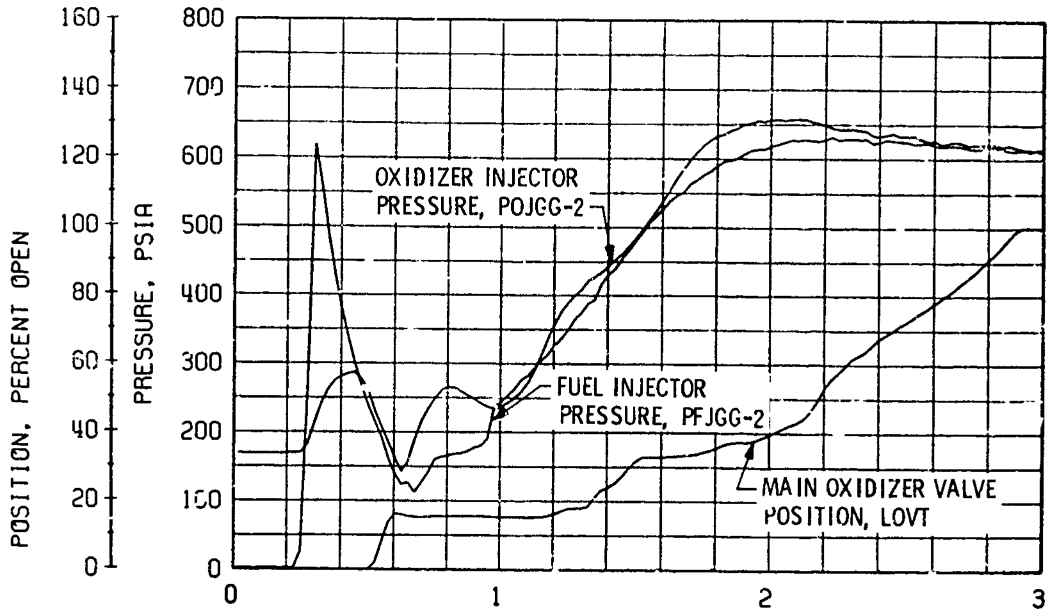


c. Thrust Chamber Fuel System, Shutdown

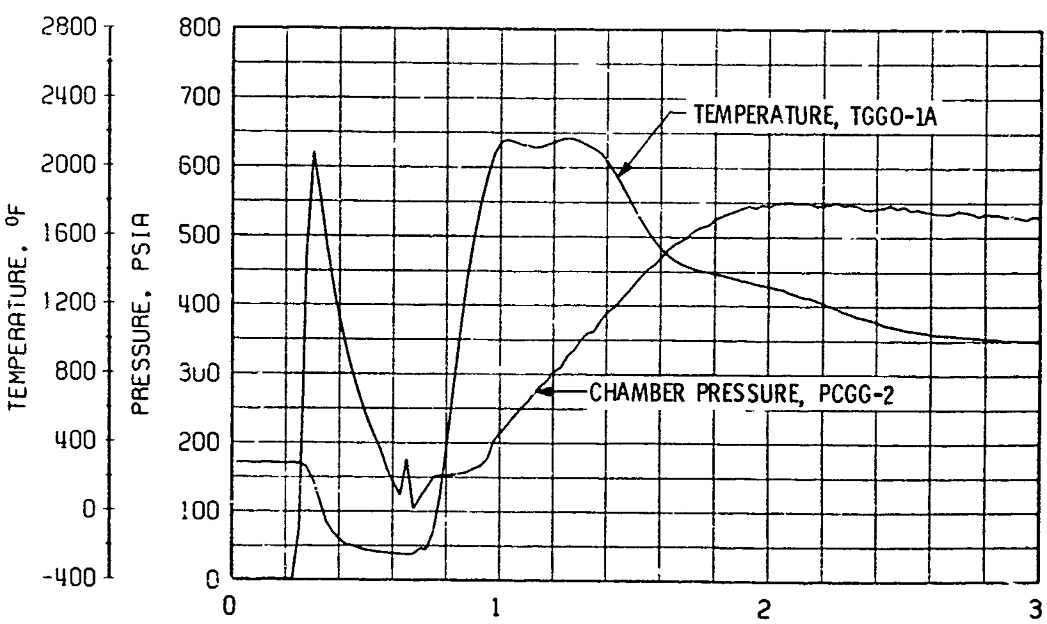


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 13 Continued

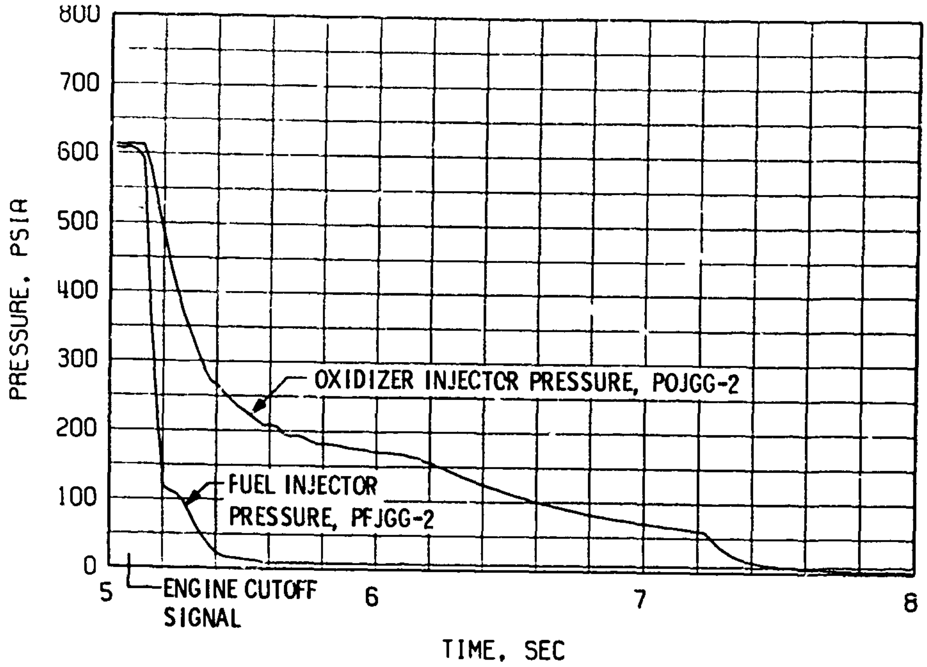


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

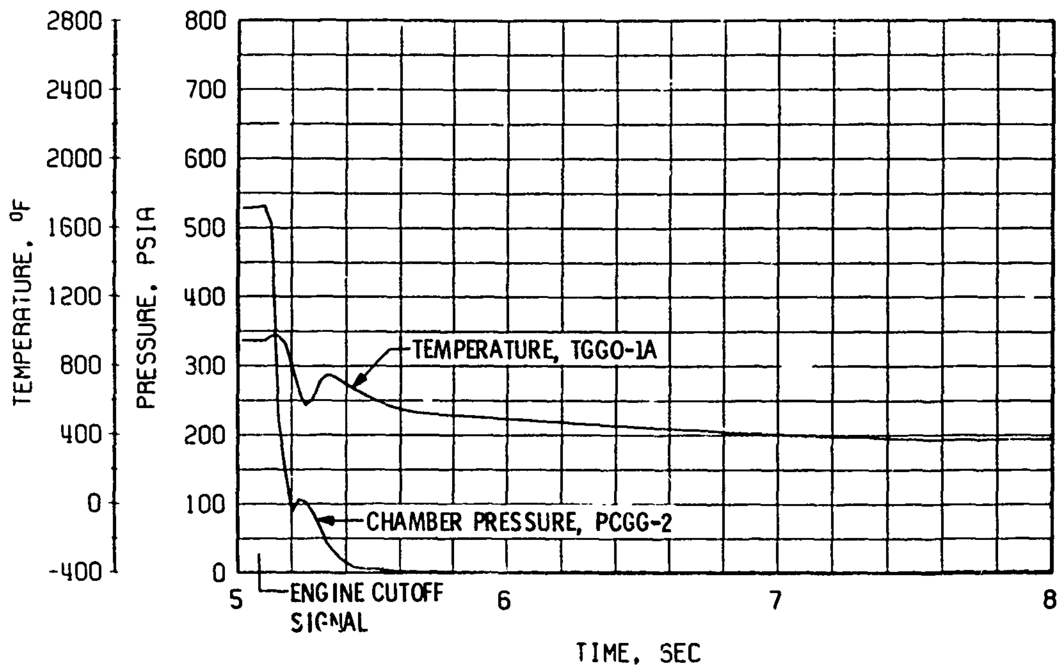


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 13 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 13 Concluded

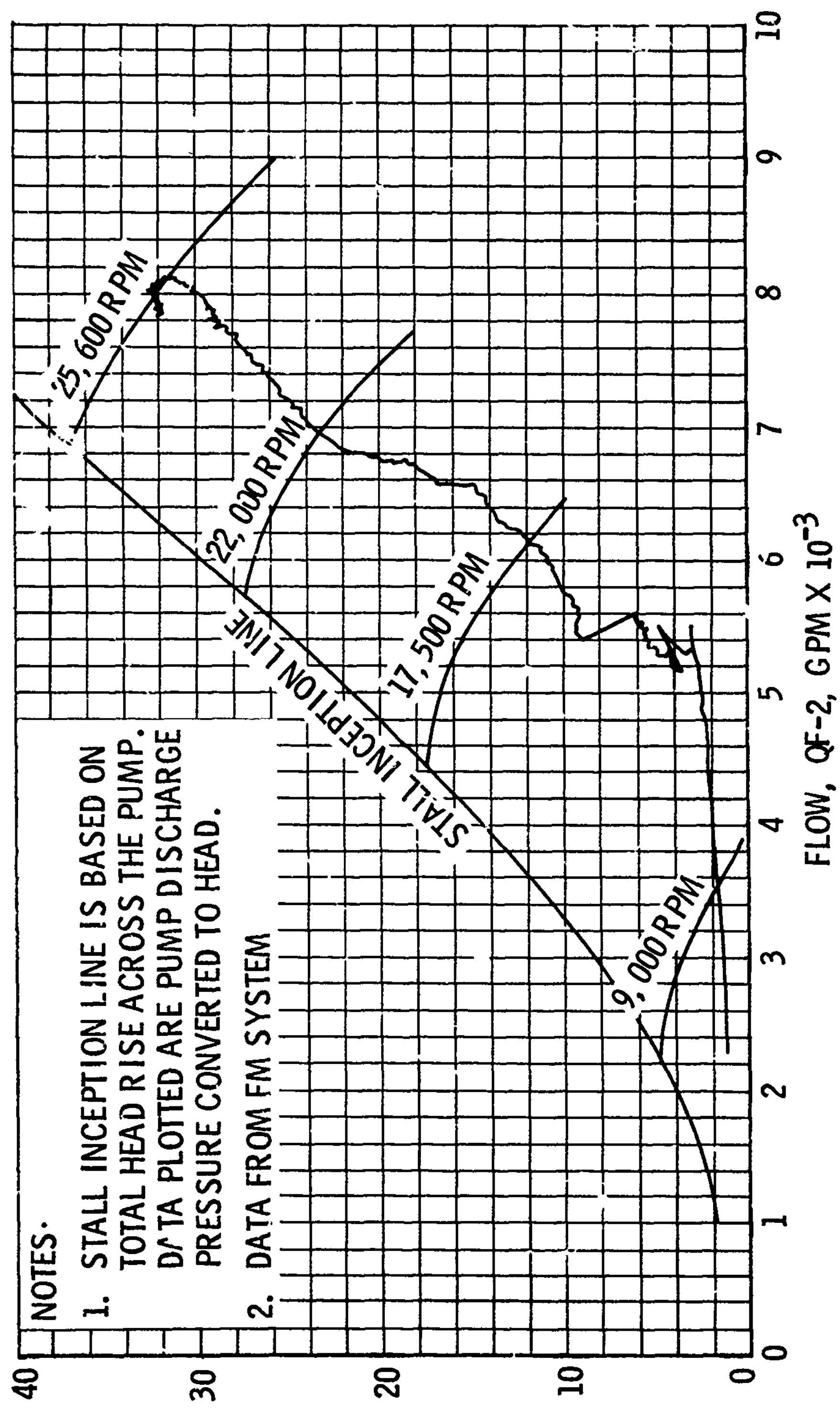


Fig. 14 Fuel Pump Start Transient Performance, Firing 06B

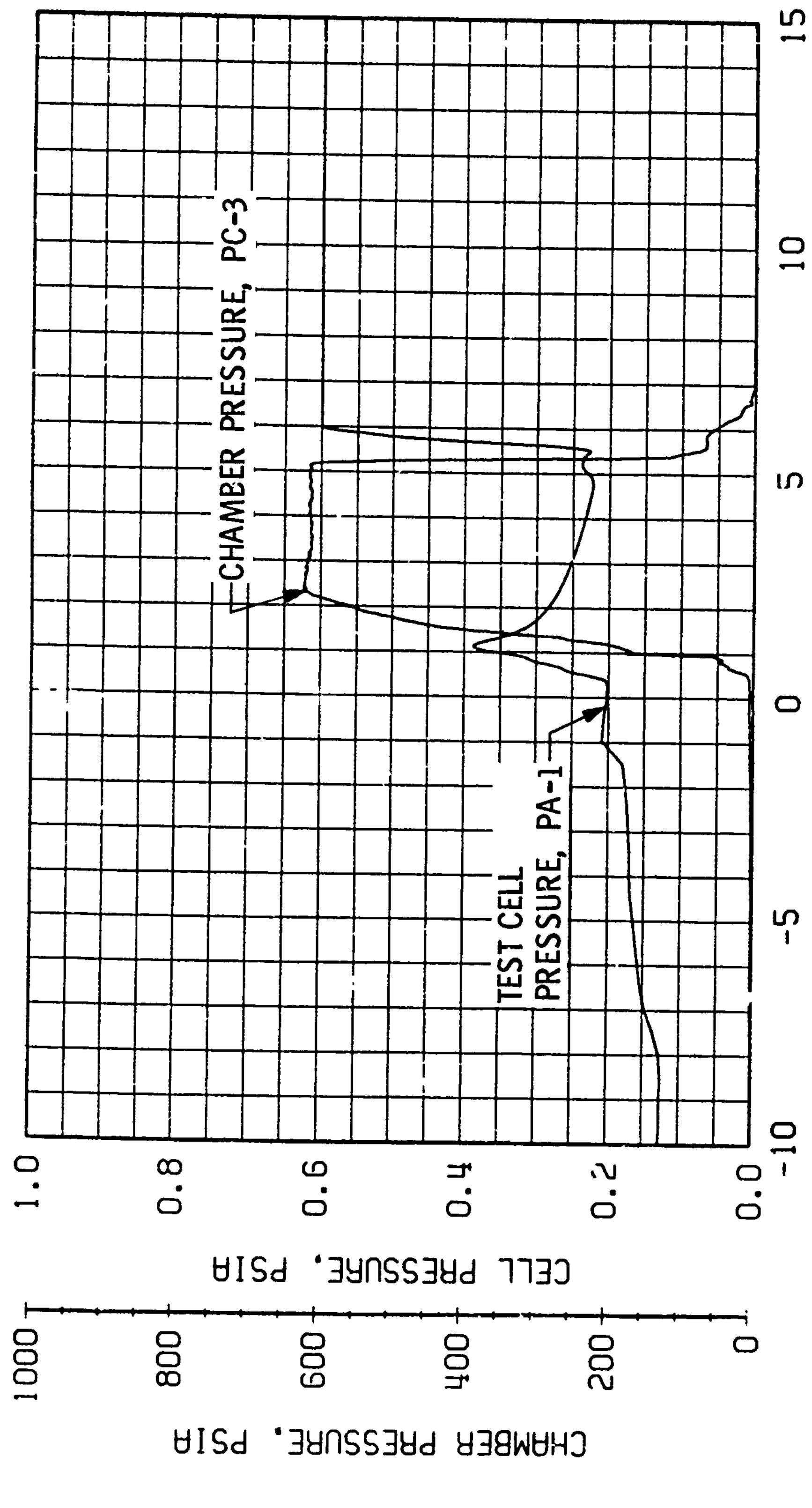


Fig. 15 Engine Ambient and Combustion Chamber Pressure, Firing 06B

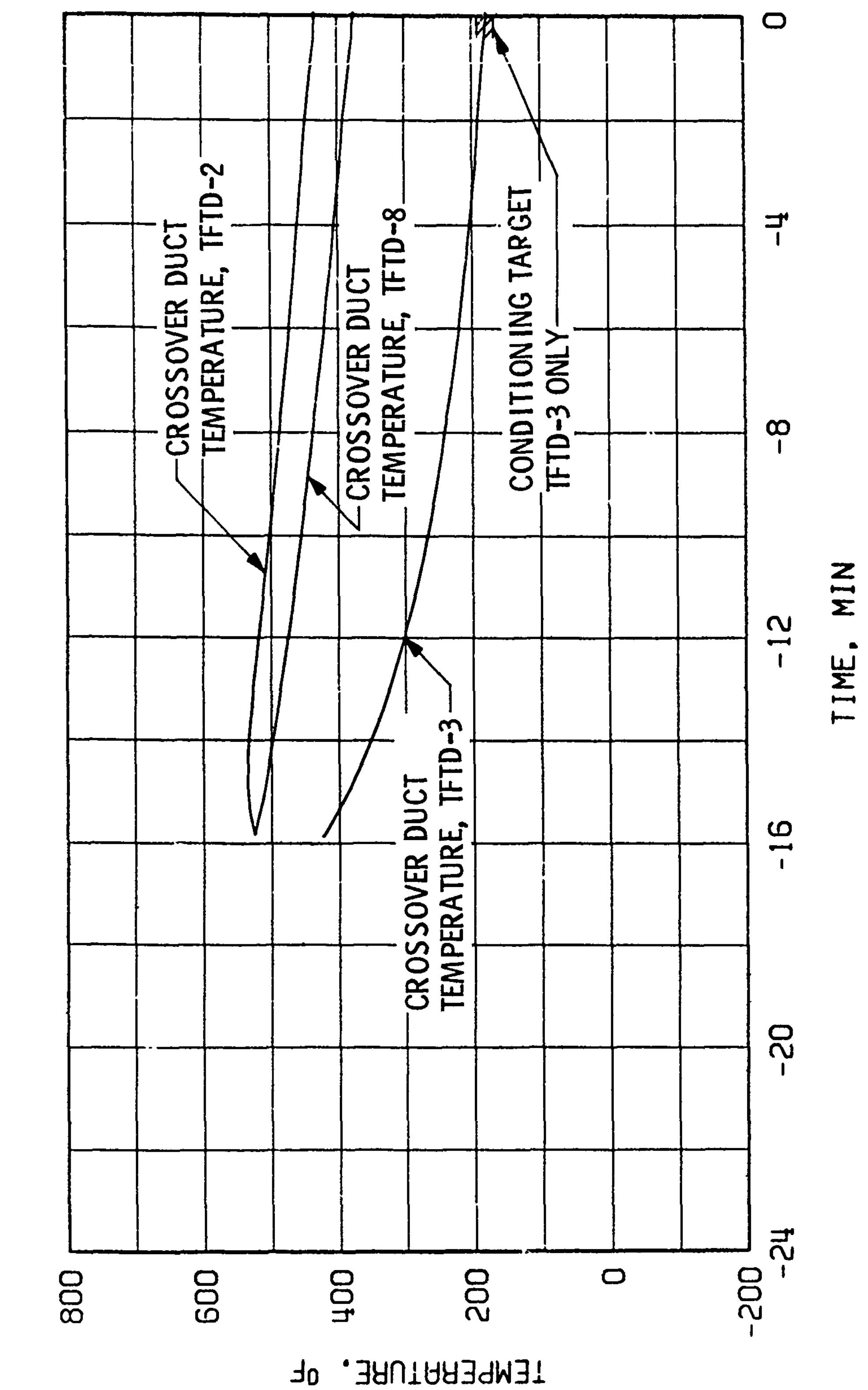
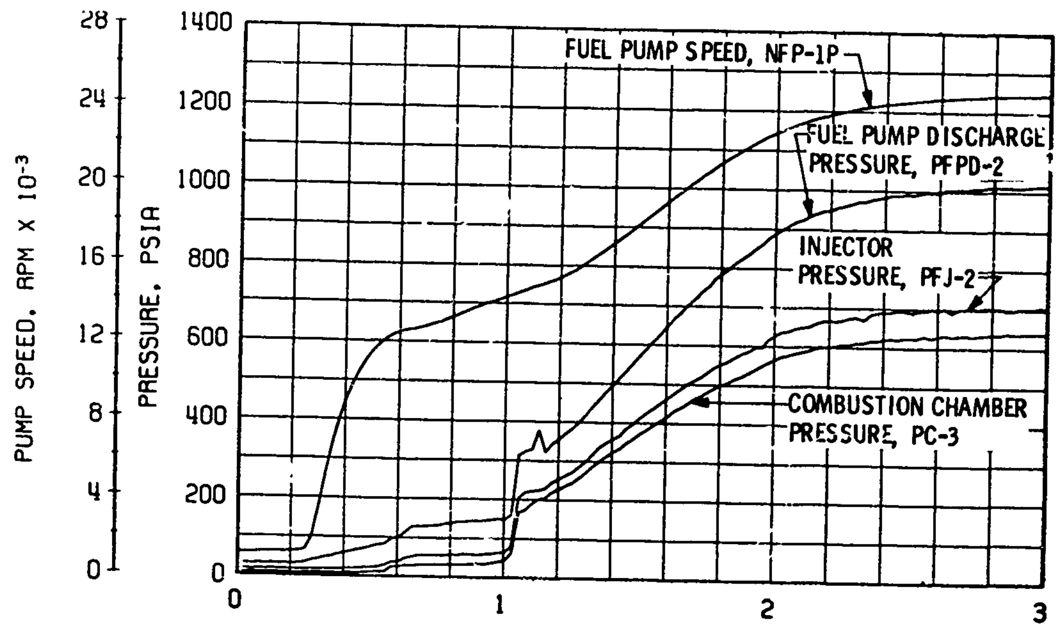
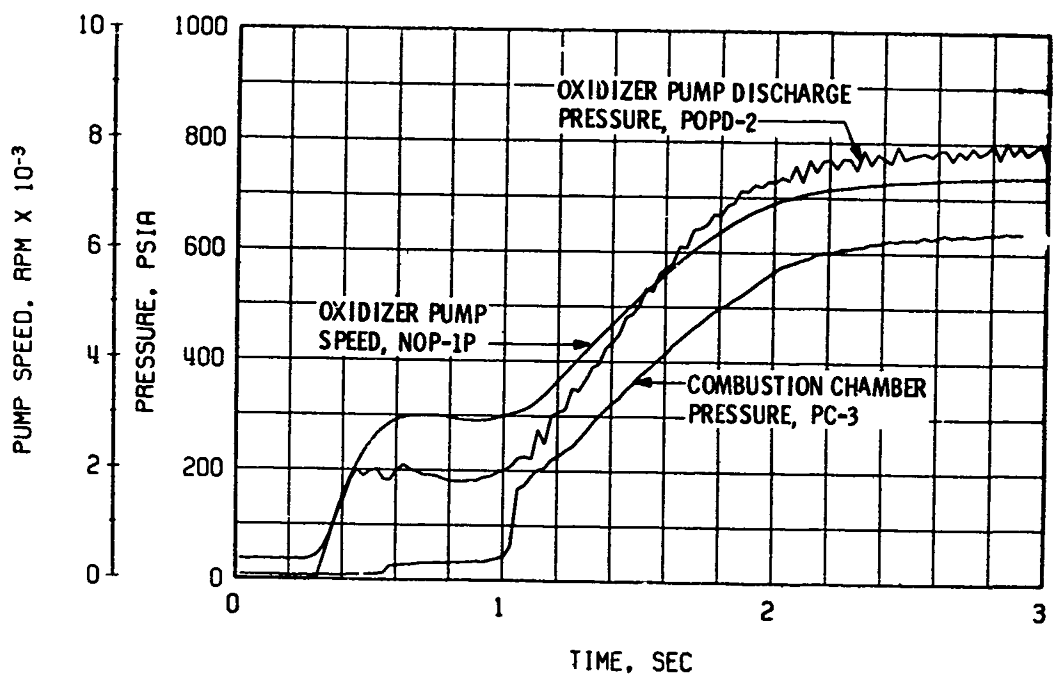


Fig. 16 Thermal Conditioning History of Engine Components, Prefire 06B

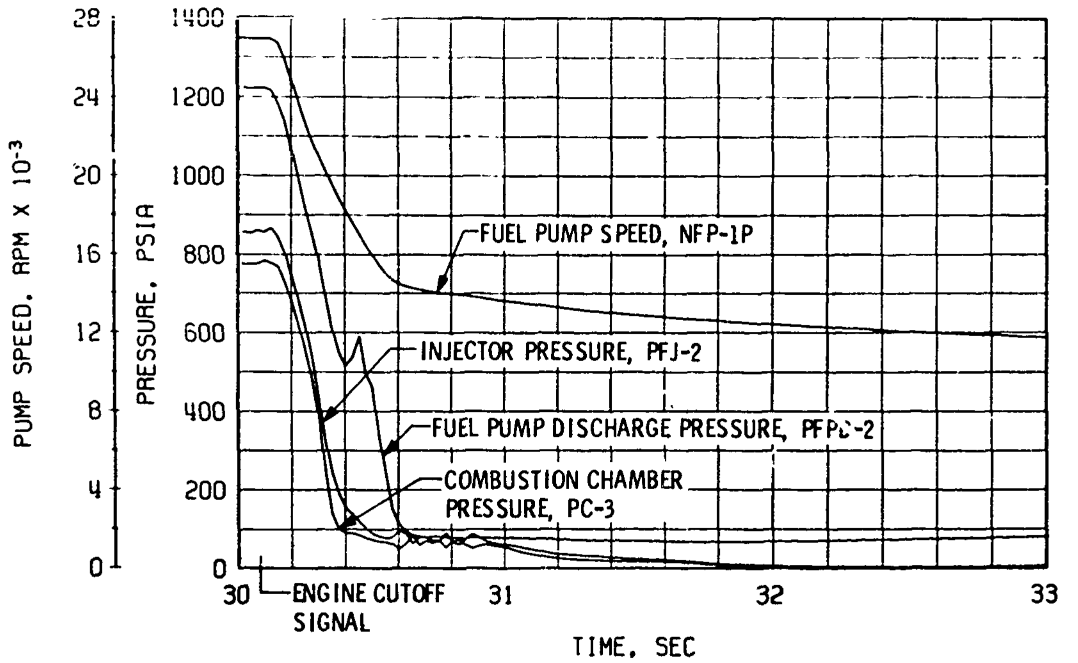


a. Thrust Chamber Fuel System, Start

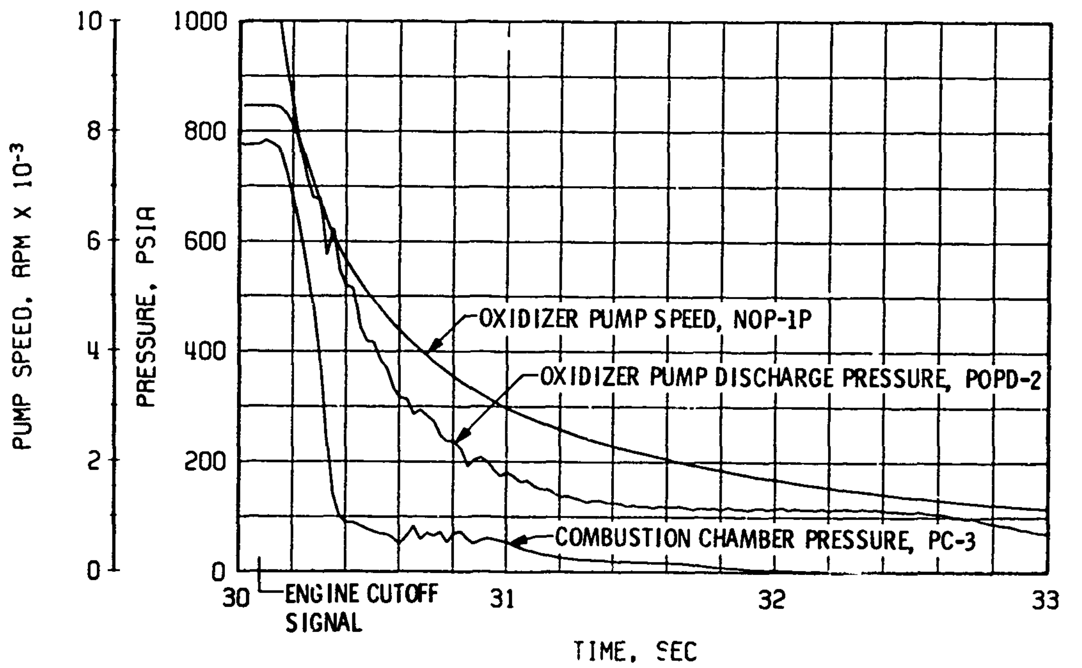


b. Thrust Chamber Oxidizer System, Start

Fig. 17 Engine Transient Operation, Firing 06C

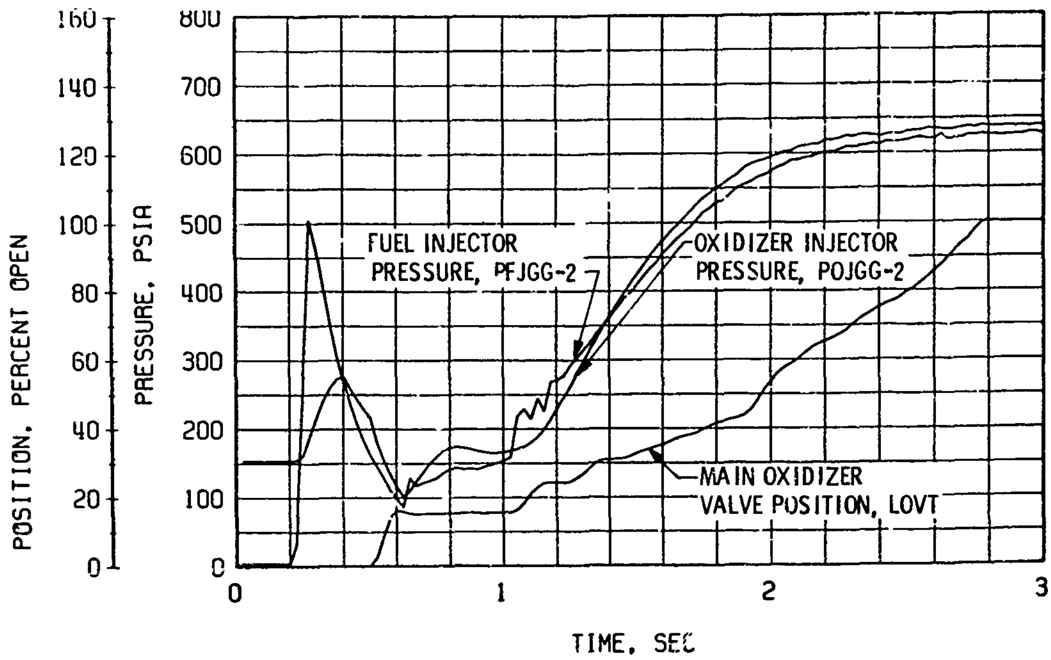


c. Thrust Chamber Fuel System, Shutdown

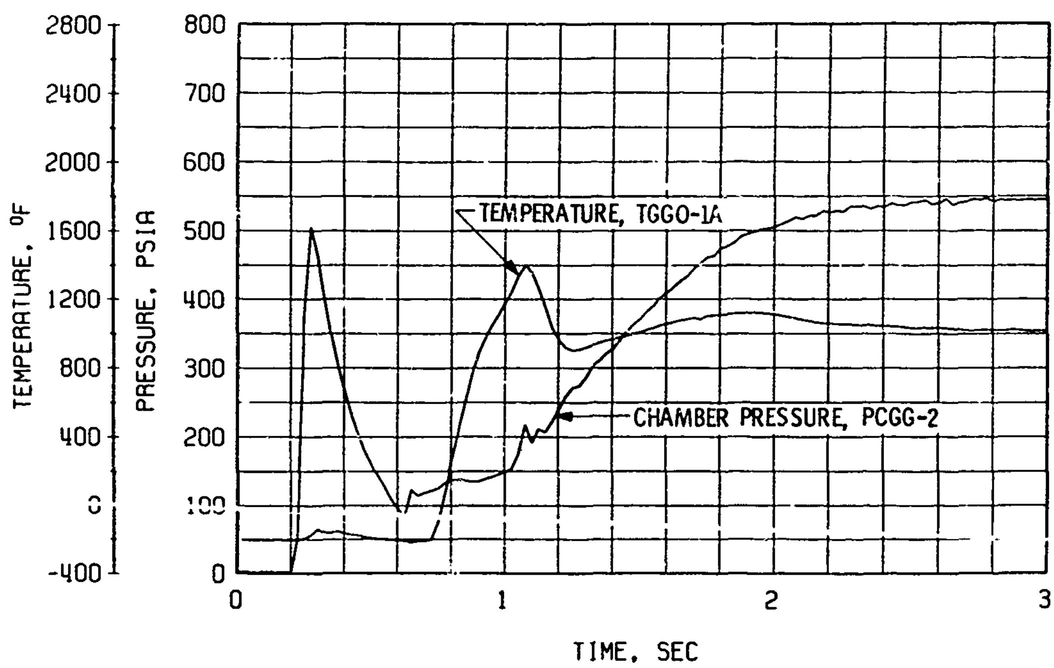


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 17 Continued

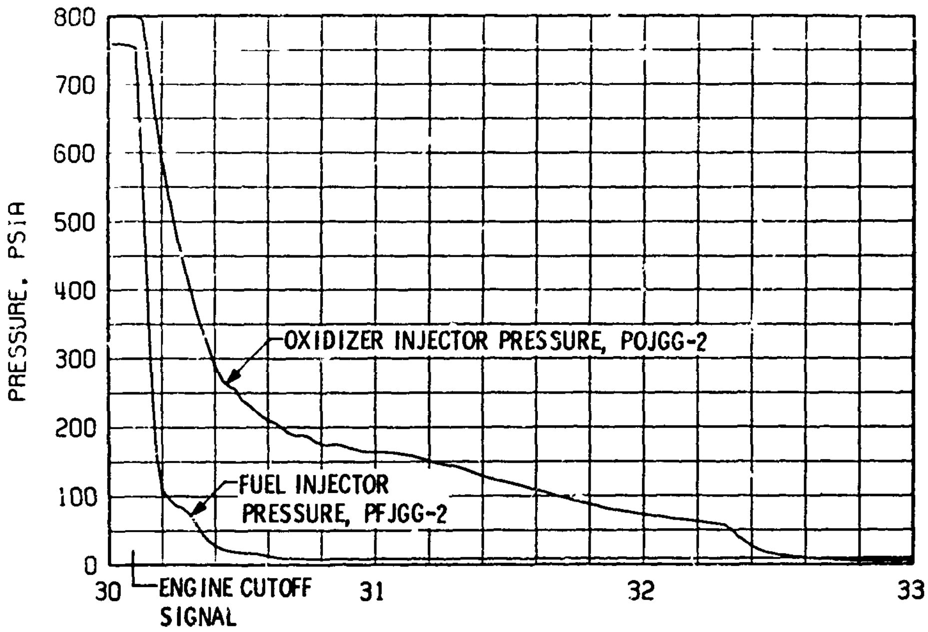


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

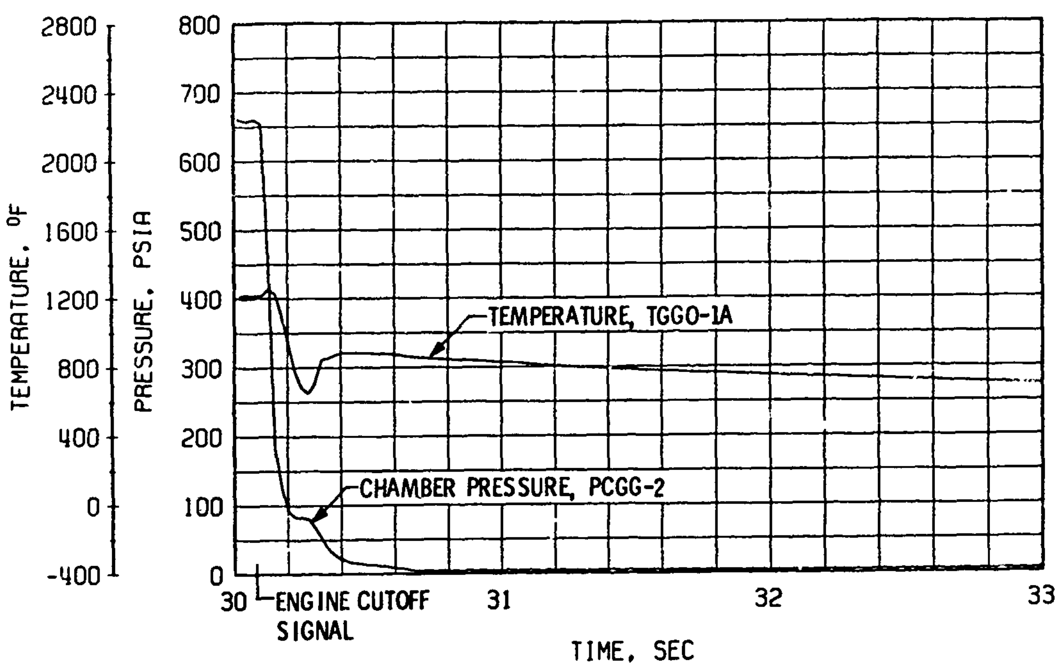


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 17 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 17 Concluded

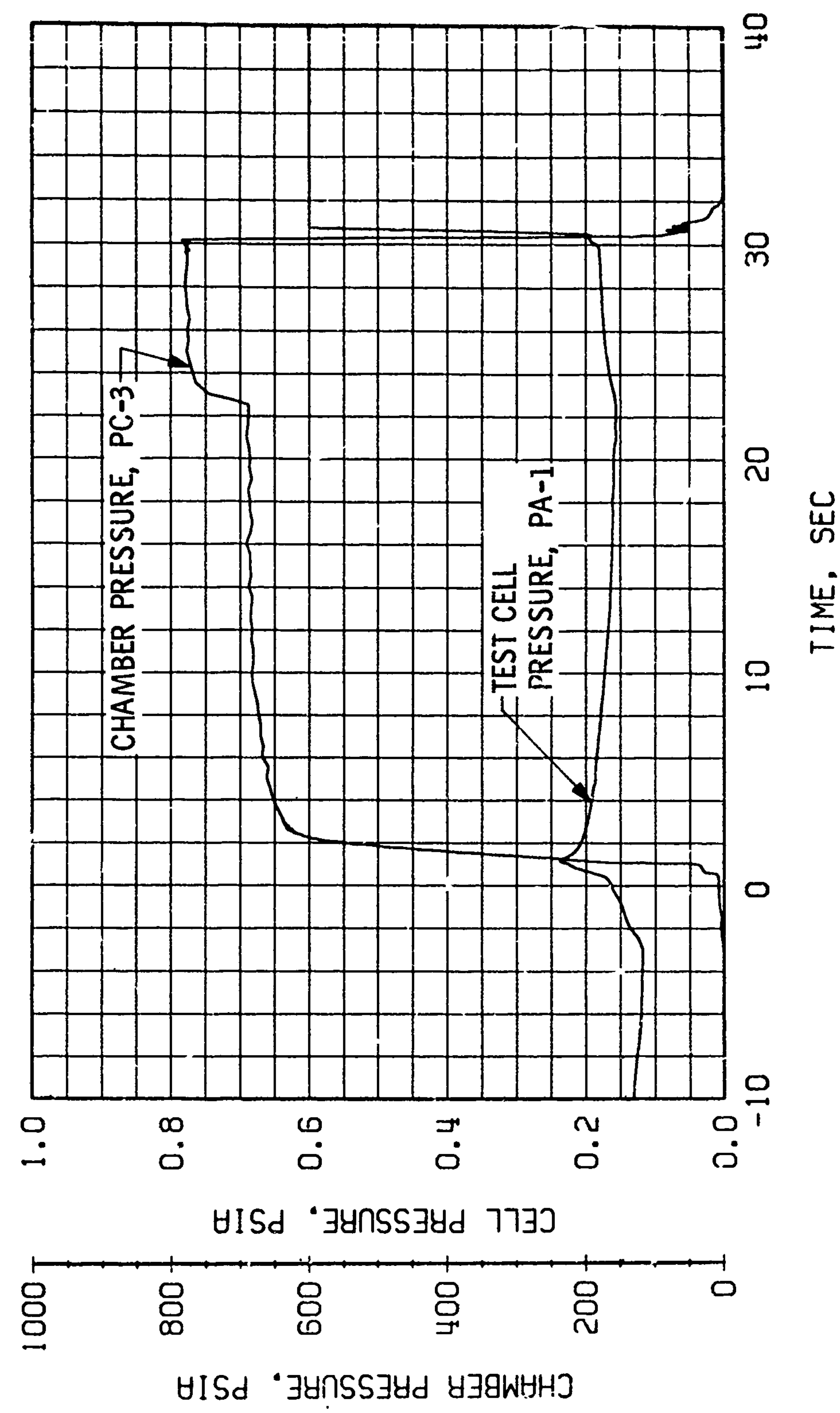
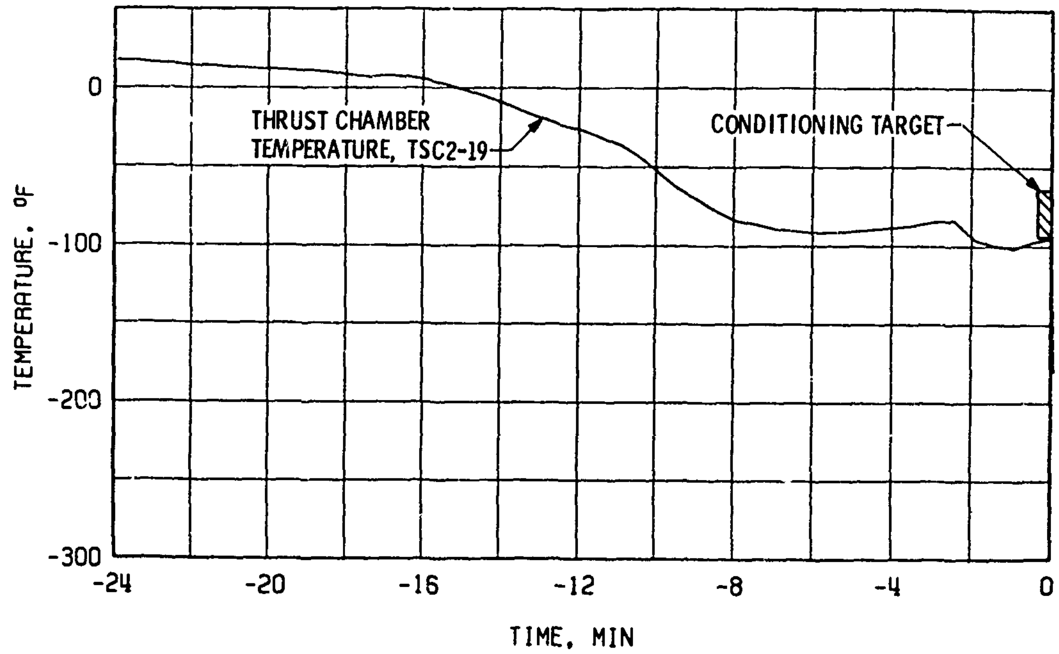
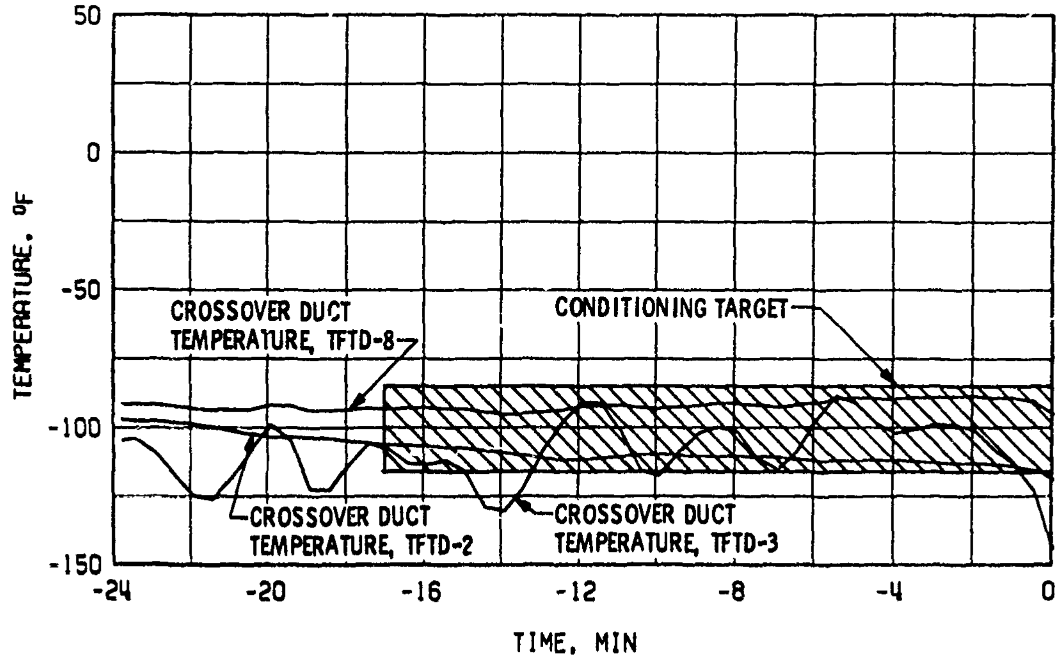


Fig. 18 Engine Ambient and Combustion Chamber Pressures, Firing 06C

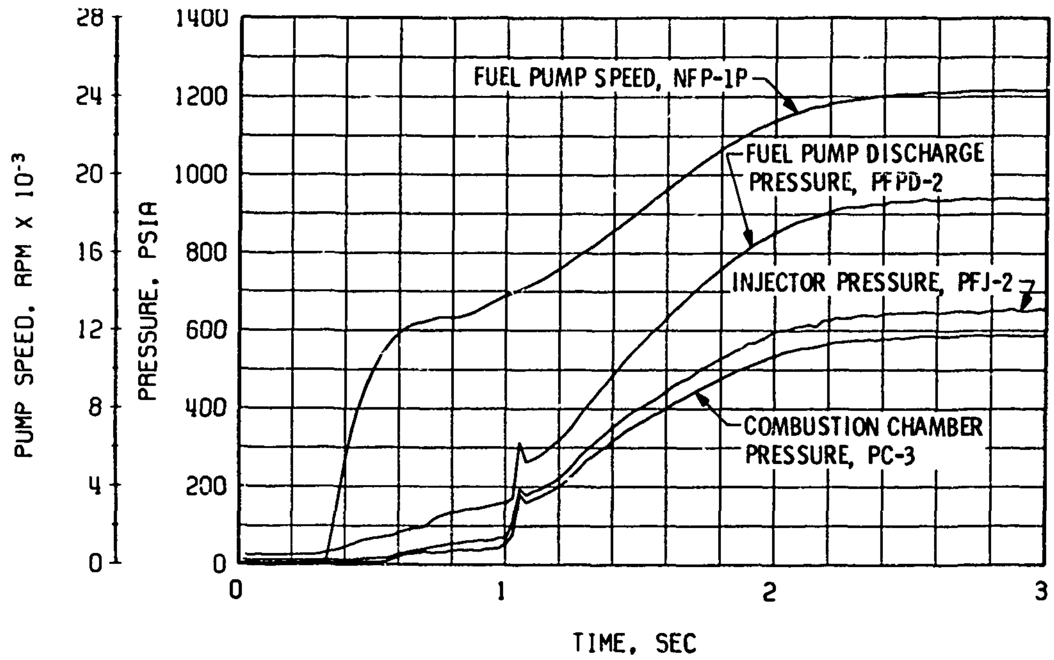


a. Thrust Chamber

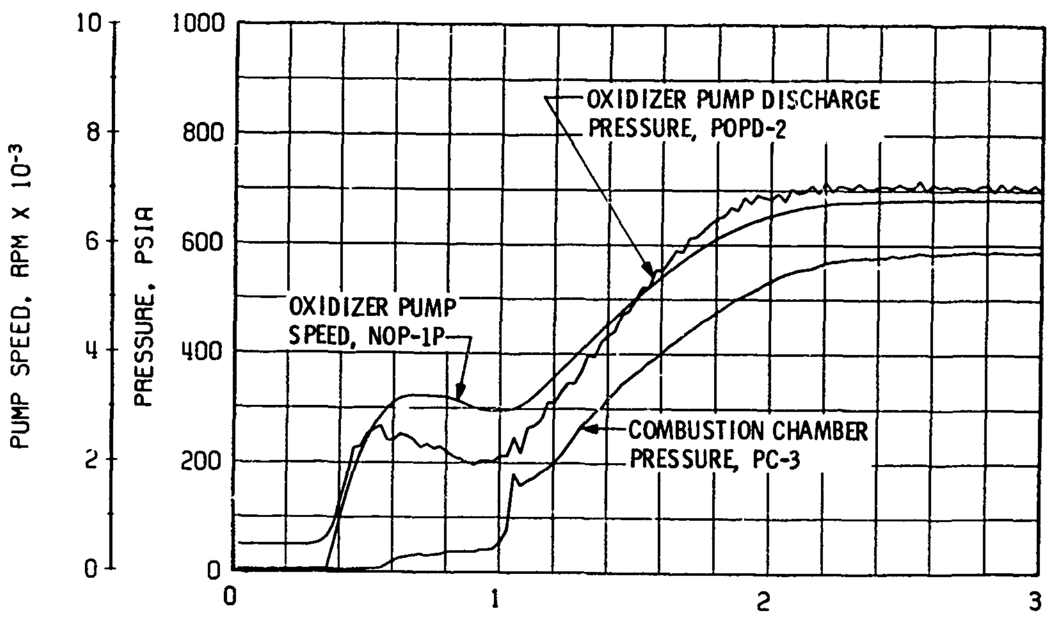


b. Turbines and Crossover Duct

Fig. 19 Thermal Conditioning History of Engine Components, Prefire 06C

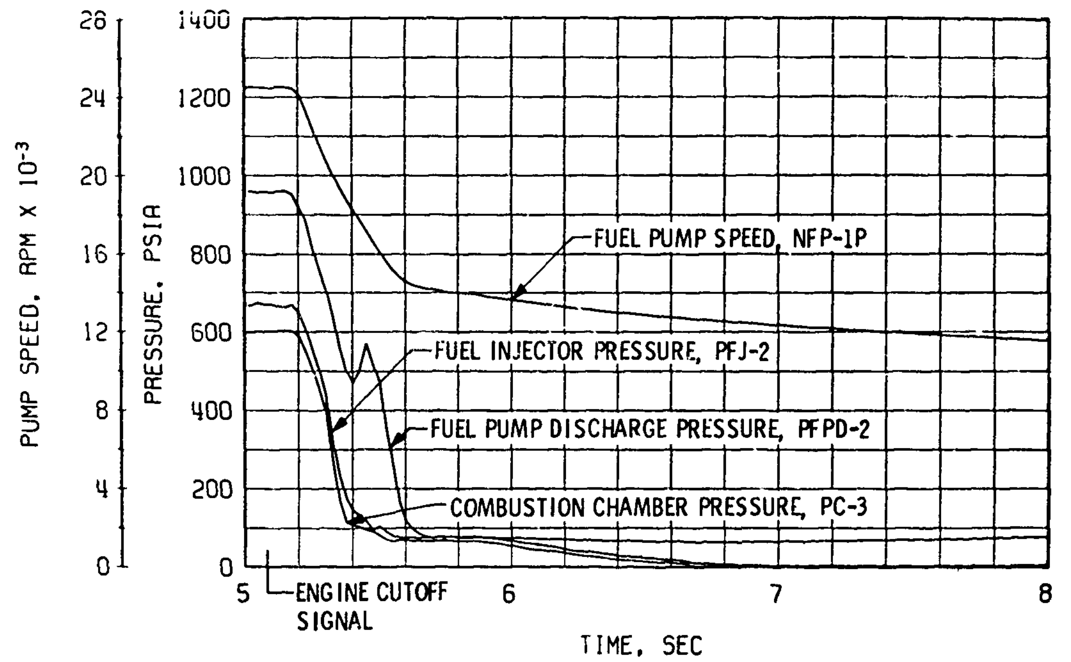


a. Thrust Chamber Fuel System, Start

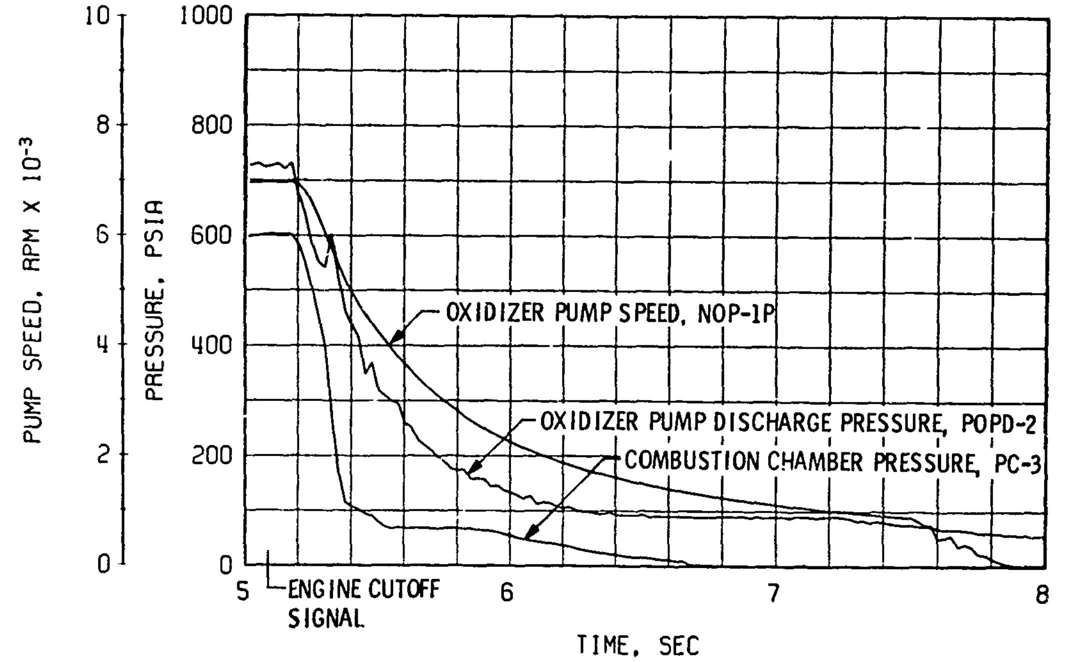


b. Thrust Chamber Oxidizer System, Start

Fig. 20 Engine Transient Operation, Firing 06D

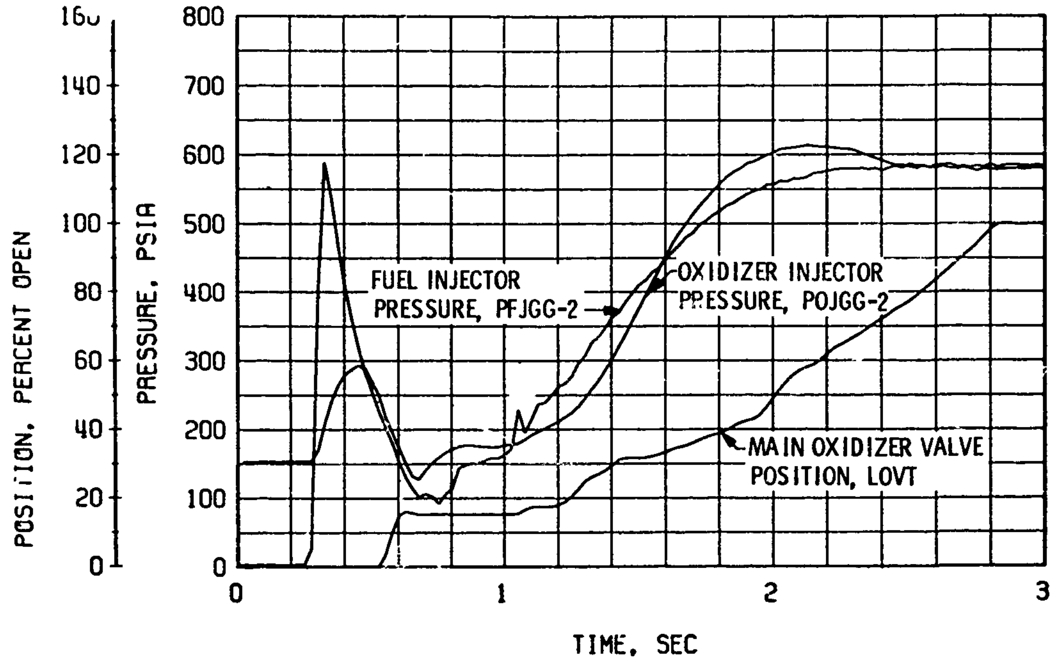


c. Thrust Chamber Fuel System, Shutdown

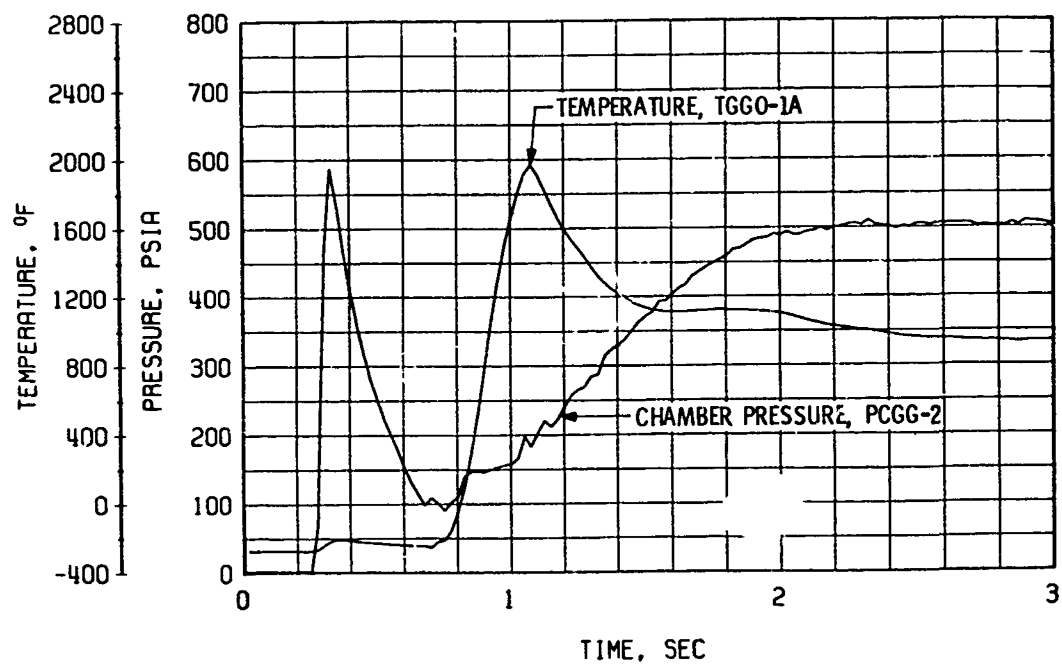


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 20 Continued

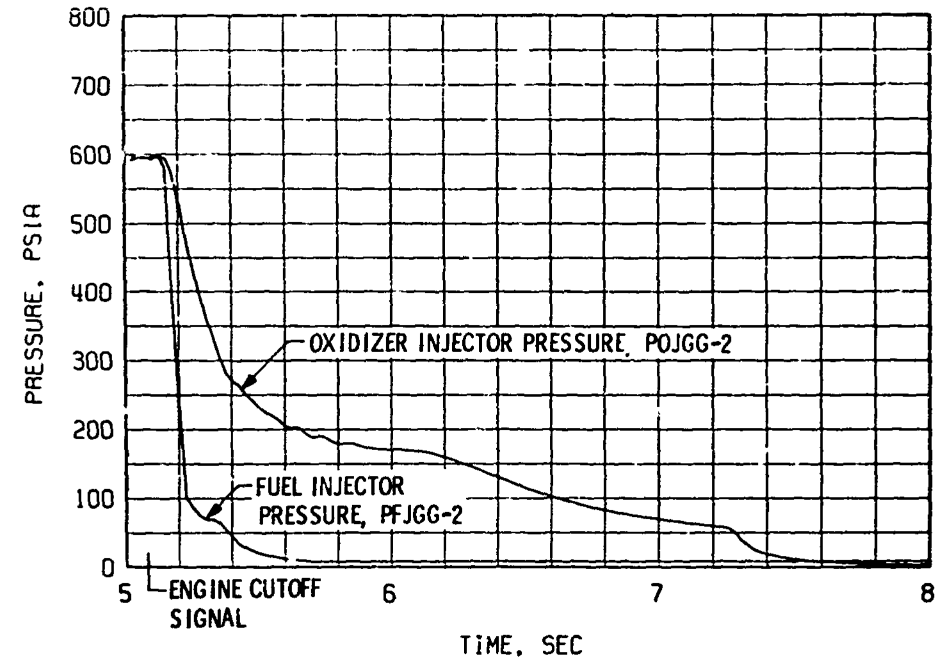


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

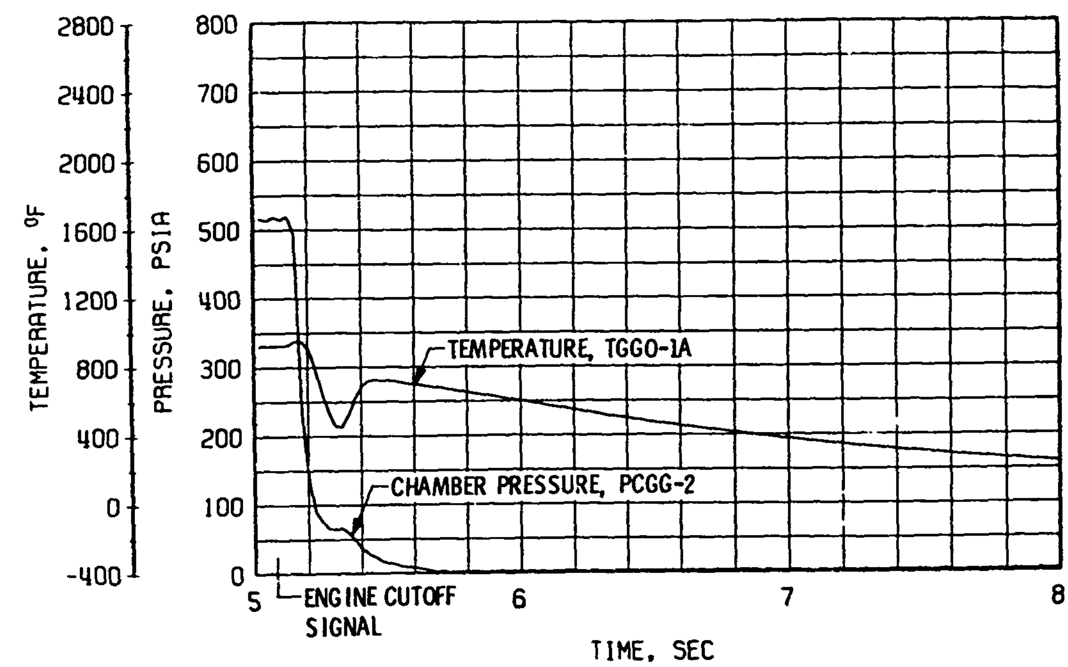


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 20 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 20 Concluded

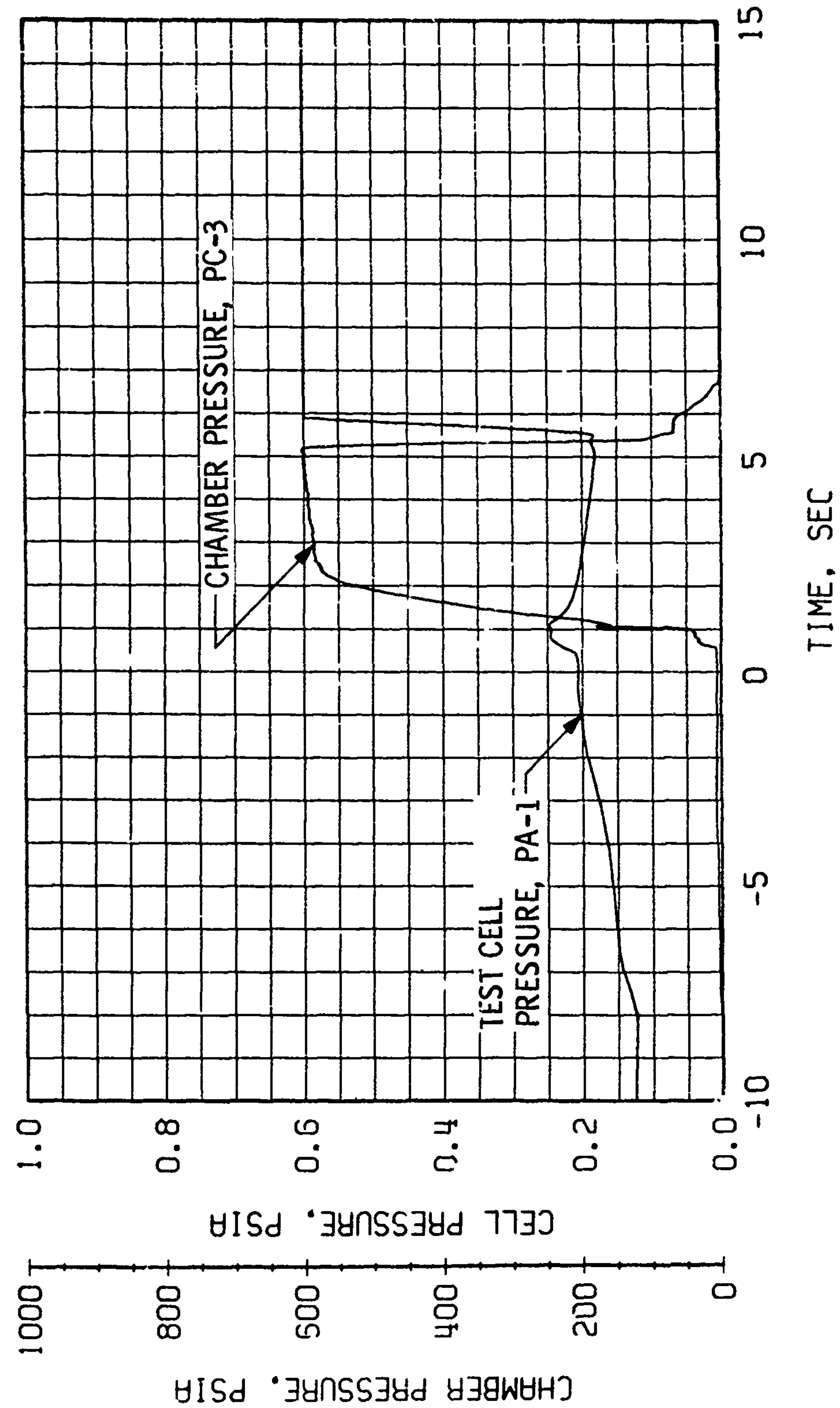


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 06D

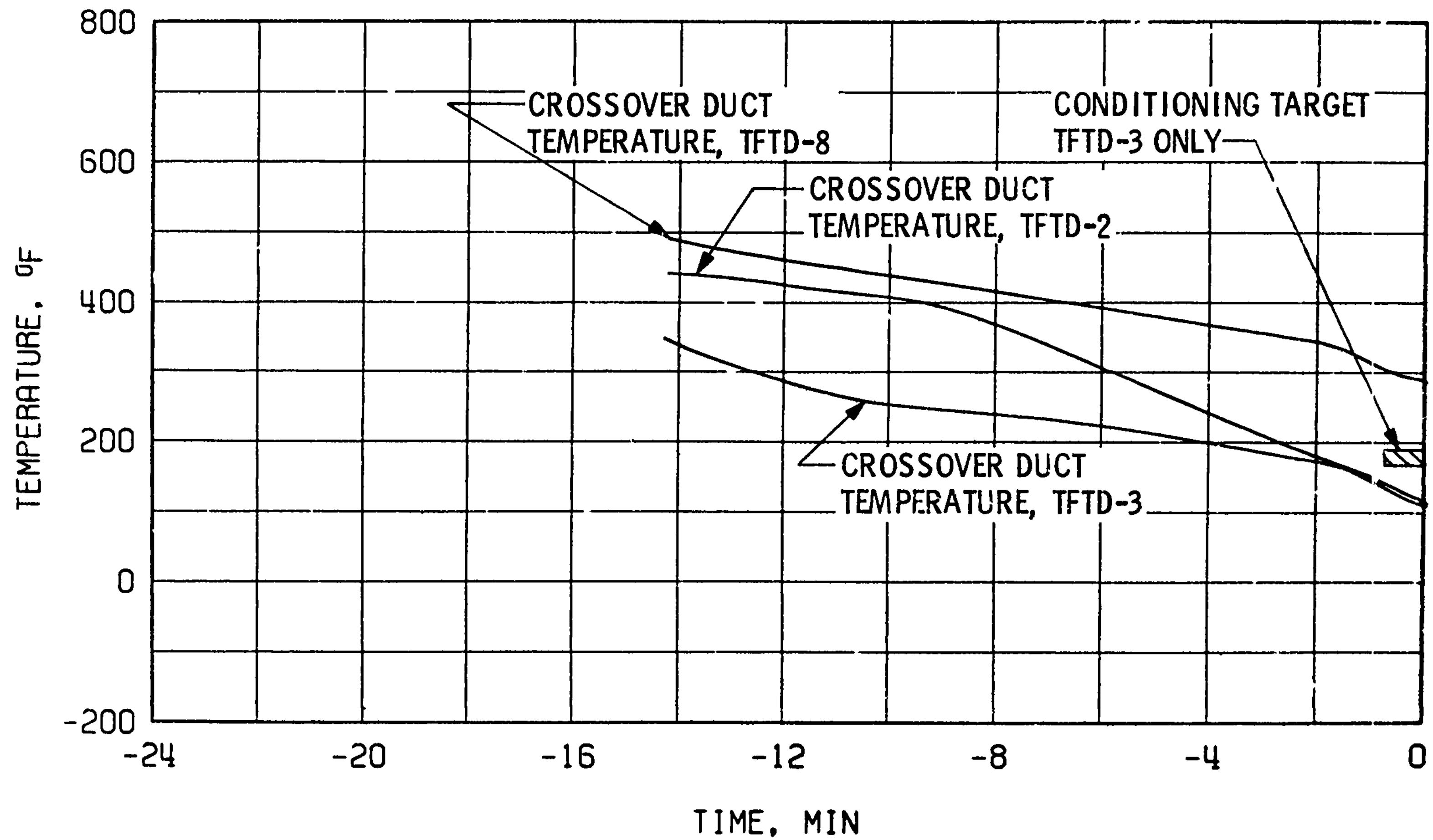


Fig. 22 Thermal Conditioning History of Engine Components, Prefire 06D

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-161	4062085
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303139	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	508360-11	4066541
Pneumatic Control Assembly	558130-41	4092999
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Phase Control Valve	558069	8275775
Helium Control Valve	106012000	342270
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XREO915389	211

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter (Except as Noted)
Gas Generator Fuel	RD 251-4107	0.480 in.
Gas Generator Oxidizer	RD 251-4106	0.281 in.
Oxidizer Turbine Bypass Valve	RD 273	1.571 in.
Main Oxidizer Valve Closing Control	556443	8.34 scfm
Turbine Exhaust	RD 251-9004	9.99 in.
Augmented Spark Igniter Oxidizer	4063461	0.137 in. 0.125 in.

TABLE III
ENGINE MODIFICATIONS
(Between Tests J4-1801-05 and J4-1801-06)

Modification Number	Completion Date	Description of Modification
ECP 507	August 18, 1967	Remove Instrumentation Line (PGBNI)

ECP - Rocketdyne Engineering Change Proposal

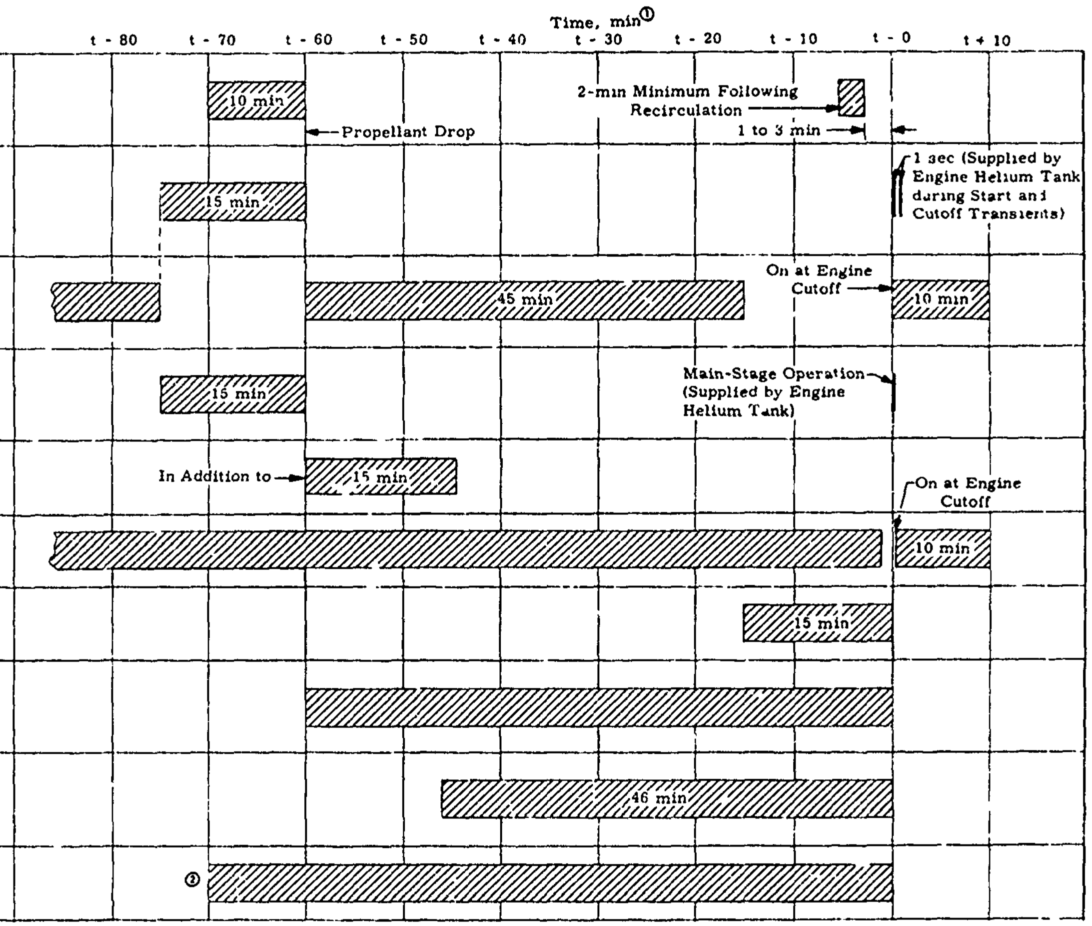
TABLE IV
ENGINE COMPONENT REPLACEMENTS
(Between Tests J4-1801-05 and J4-1801-06)

Replacement	Completion Date	Component Replaced
UCR-007982	August 18, 1967	Fuel Turbopump Assembly

UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium, 82 - 125 psia 30 - 200°F (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen, 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen, 400 - 450 psig 100 - 200°F (Nominal) 200 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium, 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect) Panel	Helium, 40 - 60 psig 50 - 200°F (Nominal) 60 scfm
	Helium, 12 - 14 psig 50 - 200°F (Nominal) 10 scfm
Thrust Chamber Temperature Conditioning	Helium, 1000 psig -300°F to Ambient 10 - 20 lb_m/min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer, 35 to 48 psia -298 to -280°F Fuel, 28 to 46 psia -434 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen, 1200 to 1400 psia -200 to -140°F Helium, 1700 to 3250 psia -300 to -140°F
Crossover Duct Temperature Conditioning	Helium, -300°F to Ambient



(1) Conditioning temperature to be maintained for the last 30 min of pre-fire

(2) Component conditions to be maintained within limits for last 15 min prior to engine start

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number J4 1801-		06A Target	06A Actual	06B Target	06B Actual	06C Target	06C Actual	06D Target	06D Actual
Time of Day hr/Firing Date		1334/August 22, 1967		[illegible]/August 22, 1967		1603/August 22, 1967		1621/August 22, 1967	
Pressure Altitude at Engine Start ft (Ref 1)			[illegible],000		108,000	-	107,000		106,000
Firing Duration sec[1]		30.0	30.072	[illegible]	5.086	30.0	30.072	5.0	5.088
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	2[illegible].0 ± 1.0	2[illegible].7	[illegible]8.0 ± 1.0	27.[illegible]	46.0 ± 1.0	45.4	46.0 ± 1.0	44.6
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.[illegible]	421.1 ± 0.4	-421.2	-421.[illegible] ± 0.4	-420.8
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	35.0 ± 1.0	34.9	48.0 ± 1.0	[illegible]7.8	35.0 ± 1.0	3[illegible]	4[illegible].0 ± 1.0	48.1
	Temperature, °F	-294.0 ± 0.4	294.3	295.3 ± 0.4	29[illegible].3	-294.[illegible] ± 0.4	294.1	-295.3 ± 0.4	-295.0
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1236	1400 ± 10	1[illegible]96	1250 ± 10	1248	1400 ± 10	1402
	Temperature, °F	140 ± 10	-141.1	-[illegible]40 ± 10	-241.5	-140 ± 10	-144.9	-240 ± 10	247.6
Helium Tank Conditions at Engine Start	Pressure, psia	--	2231	--	2362		2297	-	2273
	Temperature, °F	--	-144.0		-243.5	-	-149.9	---	-243.4
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat, TSC 2-19	-200 ± 15	-212.5 / -272.7	--	37.6 / -190.3	-[illegible] ± 15	-94.5 / -160.[illegible]	---	117 / -269
	Average	---	-208 / -265	---	23.[illegible] / 170.6	---	97 / -185	---	34 / 231
Crossover Duct Temperature at Engine Start, °F	TFTD-2	-100 ± 15	-112	-	433	-100 ± 15	-118	---	118
	TFTD-3	100 ± 15	-128	170^{+15}_{0}	[illegible]78	-100 ± 15	-143	170^{+15}_{-0}	111
	TFTD-8	-100 ± 15	-91	---	376	-100 ± 15	-95	-	239
Fuel Lead Time sec[1]		3.0	3.010	8.0	7.996	3.0	3.008	8.0	8.003
Propellant in Engine Time, min		60	164	10	10	20	63	10	10
Propellant Recirculation Time, min		10	10	10	10	10	11	10	11
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS 1	--	38.0	-	7.2	---	-18.5	---	-75.6
	TOBS-2	-	26.2	---	57.7	---	35.7	---	-22.6
	TOBS-3	---	-11.6	---	32.2	--	-13.2	---	-53.0
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0[1]		--- / ---	24 / [illegible].053	--- / ---	--- / ---	--- / ---	95 / 1.032	--- / ---	18 / 1.012
Gas Generator Outlet Temperature °F	Initial Peak	--	1830	--	2160	---	1120	---	1970
	Second Peak	---	-	---	2170	---	---	---	---
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref t_0)[1]		---	1.055	-	0.942	---	1.035	---	1.008
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref t_0)[1]		---	1.005	---	1.160	---	1.038	--	1.016
Main-Stage Pressure No. 2, sec (Ref t_0)[1]		---	1.805	---	1.577	---	1.692	---	1.684
550-psia Chamber Pressure Attained, sec (Ref t_0)[1]		---	2.141	---	1.859	---	1.960	---	2.077
Propellant Utilization Valve Position at Engine Start, deg Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / ---	Open / ---	Null / Closed	Null / Closed	Open / ---	Open / ---

NOTE [1]Data reduced from oscillogram

TABLE VII
ENGINE VALVE TIMING

Firing Number J4-1801-	Start											
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
06A	0	0.149	0.141	0.416	0.092	0.257	-3.009	0.056	0.069	0.446	0.060	0.056
06B	0	0.159	0.146	0.446	0.091	0.253	-7.995	0.053	0.068	0.446	0.058	0.059
06C	0	0.154	0.136	0.446	0.094	0.264	-3.007	0.051	0.069	0.446	0.048	0.069
06D	0	0.158	0.152	0.443	0.092	0.253	-8.002	0.050	0.068	0.443	0.057	0.054
Pre-Fire Final Sequence	0	0.098	0.108	0.447	0.093	0.244	-1.012	0.041	0.071	0.447	0.050	0.050

Firing Number J4-1801-	Start											
	Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
06A	0.446	0.566	1.701	0.446	0.096	0.038	0.446	0.168	0.053	0.446	0.236	0.287
06B	0.446	0.724	1.727	0.446	0.097	0.041	0.446	0.182	0.072	0.446	0.215	0.300
06C	0.446	0.592	1.710	0.446	0.097	0.045	0.446	0.182	0.078	0.446	0.254	0.294
06D	0.443	0.570	1.768	0.443	0.097	0.057	0.443	0.194	0.082	0.443	0.221	0.316
Pre-Fire Final Sequence	0.447	0.613	1.710	0.447	0.079	0.032	0.447	0.131	0.053	0.447	0.209	0.292

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
06A	30.071	0.134	0.263	30.073	0.090	0.206	30.073	0.071	0.261	30.073	0.018	0.025	30.073	0.255	0.539
06B	5.087	0.122	0.331	5.087	0.068	0.175	5.087	0.079	0.201	5.087	0.014	0.034	5.087	0.238	0.526
06C	30.072	0.130	0.340	30.072	0.083	0.205	30.072	0.069	0.228	30.072	0.008	0.029	30.072	0.252	0.506
06D	5.088	0.119	0.321	5.088	0.070	0.197	5.088	0.087	0.189	5.088	0.017	0.039	5.088	0.238	0.502
Pre-Fire Final Sequence	---	0.088	0.241	---	0.062	0.132	---	0.086	0.050	---	0.036	0.050	---	0.234	0.608

Notes 1. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized

2. Final sequence check is conducted without propellants and within 12 hr prior to testing.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		-06A		-06C	
		Site	Normalized	Site	Normalized
Time, sec		29.5	29.5	29.5	29.5
Overall Engine Performance	Thrust, lb_f	227,000	225,000	226,000	224,000
	Chamber Pressure, psia	765.8	757.4	762.8	752.7
	Mixture Ratio	5.287	5.285	5.311	5.338
	Fuel Weight Flow, lb_m/sec	83.94	83.06	83.57	82.22
	Oxidizer Weight Flow, lb_m/sec	443.8	439.0	443.9	438.9
	Total Weight Flow, lb_m/sec	527.8	522.0	527.4	521.1
Thrust Chamber Performance	Mixture Ratio	5.481	5.481	5.506	5.537
	Total Weight Flow, lb_m/sec	520.8	515.1	520.4	514.2
	Characteristic Velocity, ft/sec	8061	8060	8034	8024
Fuel Turbopump Performance	Pump Efficiency, percent	73.5	73.5	73.5	73.5
	Pump Speed, rpm	27,025	26,859	26,954	26,689
	Turbine Efficiency, percent	60.7	60.6	(1)	(1)
	Turbine Pressure Ratio	7.47	7.47	(1)	(1)
	Turbine Inlet Temperature, °F	1234	1218	1232	1216
	Turbine Weight Flow, lb_m/sec	7.03	6.99	7.01	6.96
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.1	80.1	80.1	80.1
	Pump Speed, rpm	8482	8412	8470	8403
	Turbine Efficiency, percent	46.8	46.6	(1)	(1)
	Turbine Pressure Ratio	2.67	2.67	(1)	(1)
	Turbine Inlet Temperature, °F	764	752	754	744
	Turbine Weight Flow, lb_m/sec	6.11	6.08	(1)	(1)
Gas Generator Performance	Mixture Ratio	0.960	0.950	0.959	0.949
	Chamber Pressure, psia	654.9	649.3	652.3	645.9

Site - Test Data

Normalized - Test data corrected to standard pump inlet and engine ambient pressure conditions.

NOTE: (1) Calculation invalidated by loss of POTI-1A measurement.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC Test J4-1801-06 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		on/off	x		x		
EECO	Engine Cutoff Signal		on/off	x	x	x		
EES	Engine Start Command		on/off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		open/closed	x				
EFJT	Fuel Injector Temperature OK		on/off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		closed/open	x				
EHCS	Helium Control Solenoid		on/off	x		x		
EID	Ignition Detected		on/off	x		x		
EIPCS	Ignition Phase Control Solenoid		on/off	x		x		
EMCS	Main-Stage Control Solenoid		on/off	x		x		
EMP-1	Main-Stage Pressure OK, No. 1		on/off	x		x		
EMP-2	Main-Stage Pressure OK, No. 2		on/off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		open/closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		on/off	x	x	x		
	Spark Rates							
RASIS-1	Augmented Spark Igniter Spark No 1		on/off			x		
RASIS-2	Augmented Spark Igniter Spark No 2		on/off			x		
RGGS-1	Gas Generator Spark No 1					x		
RGGS-2	Gas Generator Spark No 2					x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-2SD	Fuel Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Forces		lb_f					
FSP-1	Side Load (Pitch)		±20,000	x		x		
FSY-1	Side Load (Yaw)		±20,000	x		x		
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCASI-2	Augmented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-1P	Gas Generator Chamber	GG1	0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	

TABLE III-1 (Continued)

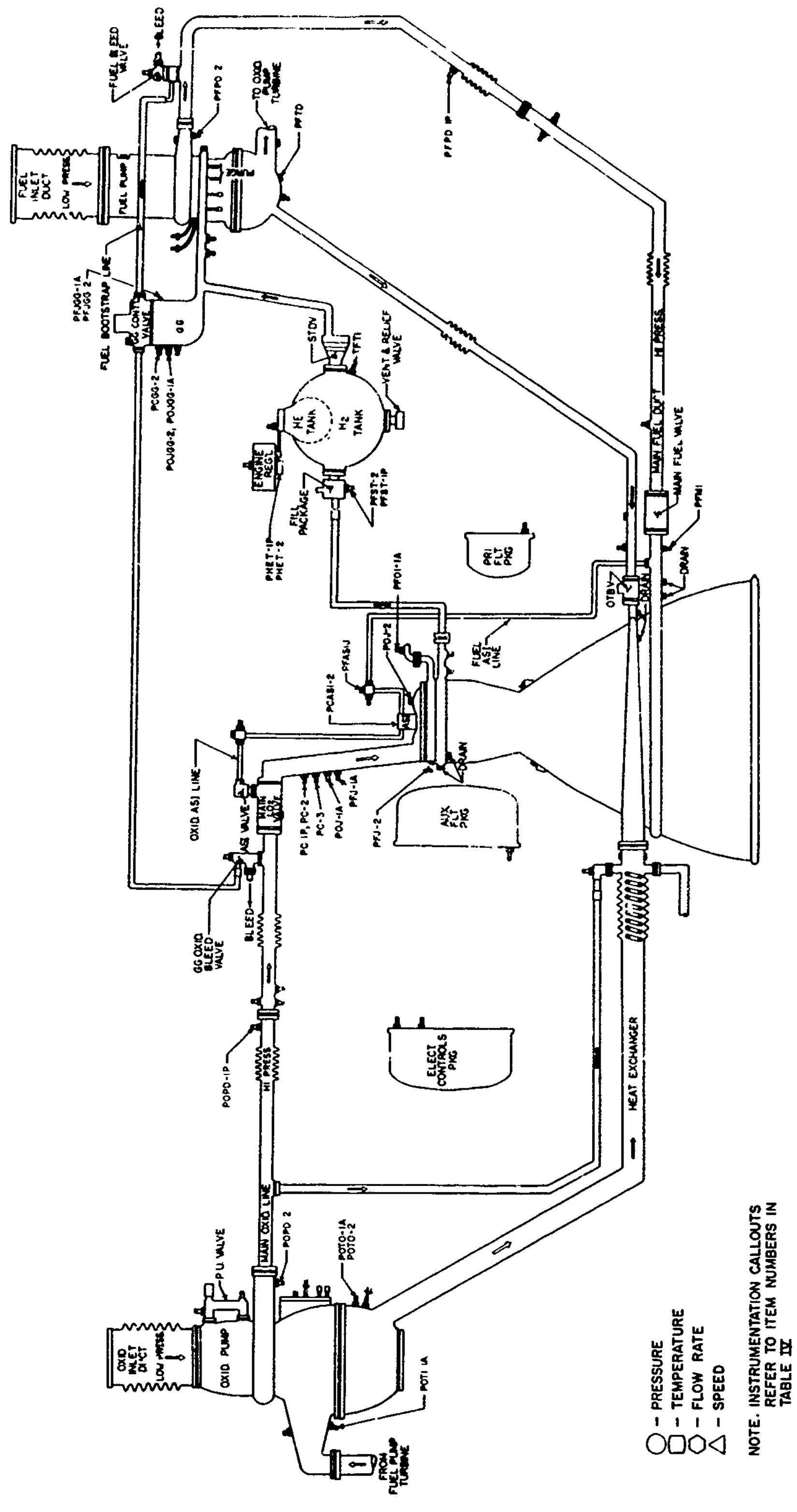
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Fuel Line		-300 to +200	x			x	
TFASIL-2	Augmented Spark Igniter Fuel Line		-300 to +200	x			x	
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPB-1A	Fuel Pump Bearing		-425 to -325	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	Oxidizer Dome Purge		0 to +300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				

TABLE III-1 (Continued)

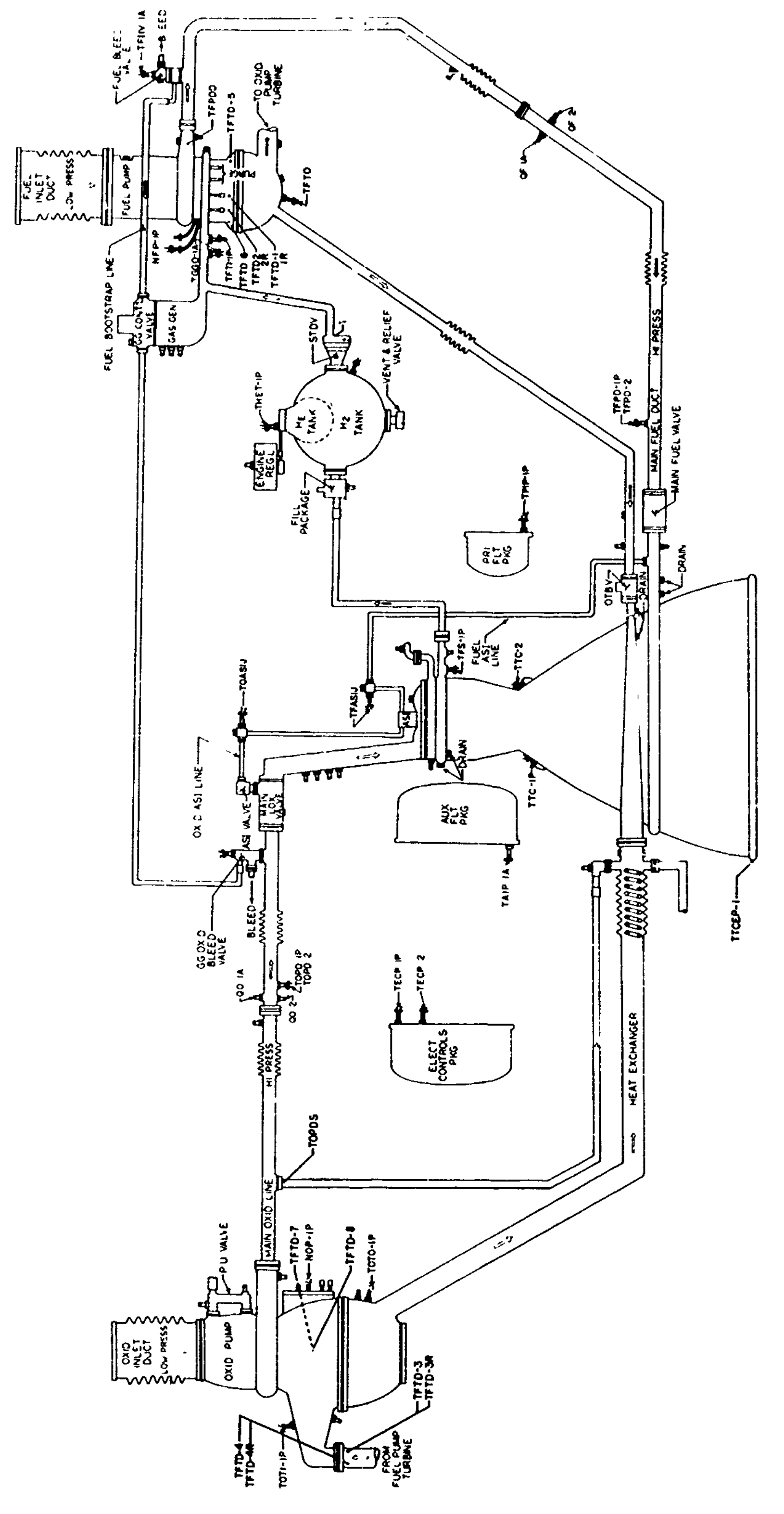
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSECP	Skin, Electrical Control Package		-50 to +250	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSPIP	Skin, Primary Instrument Package		-50 to +250	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No 1 Vibration Safety Counts		on/off			x		
U2VSC	No 2 Vibration Safety Counts		on/off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

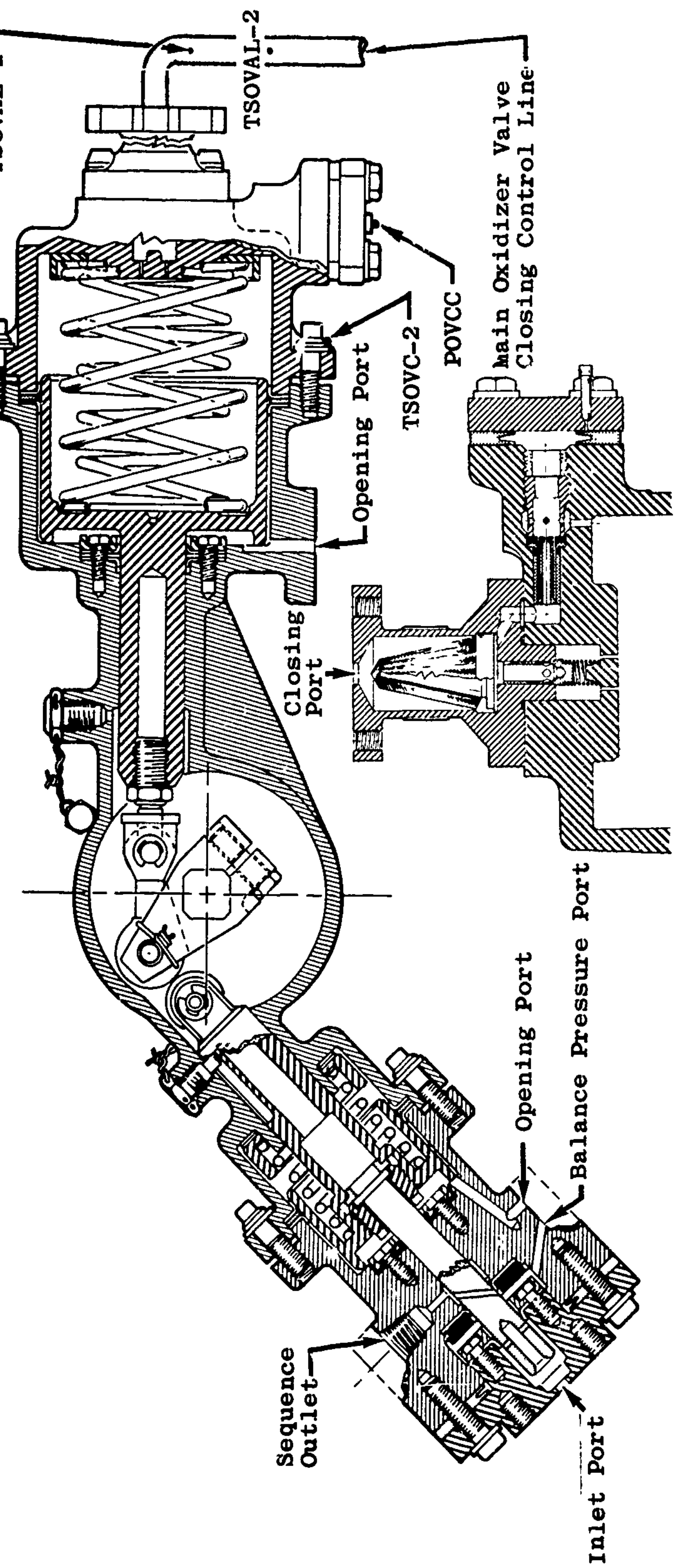


a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations

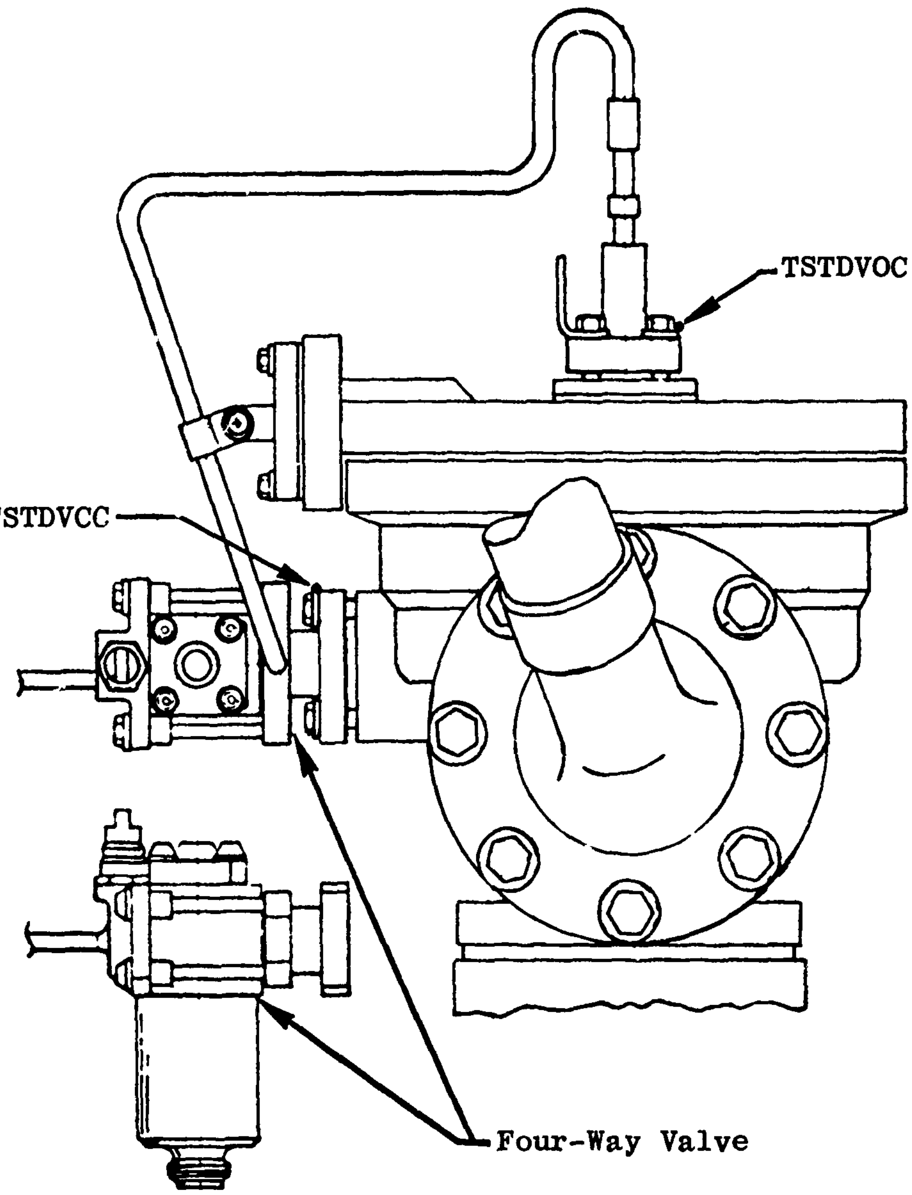


b. Engine Temperature, Flow, and Speed Instrumentation Locations

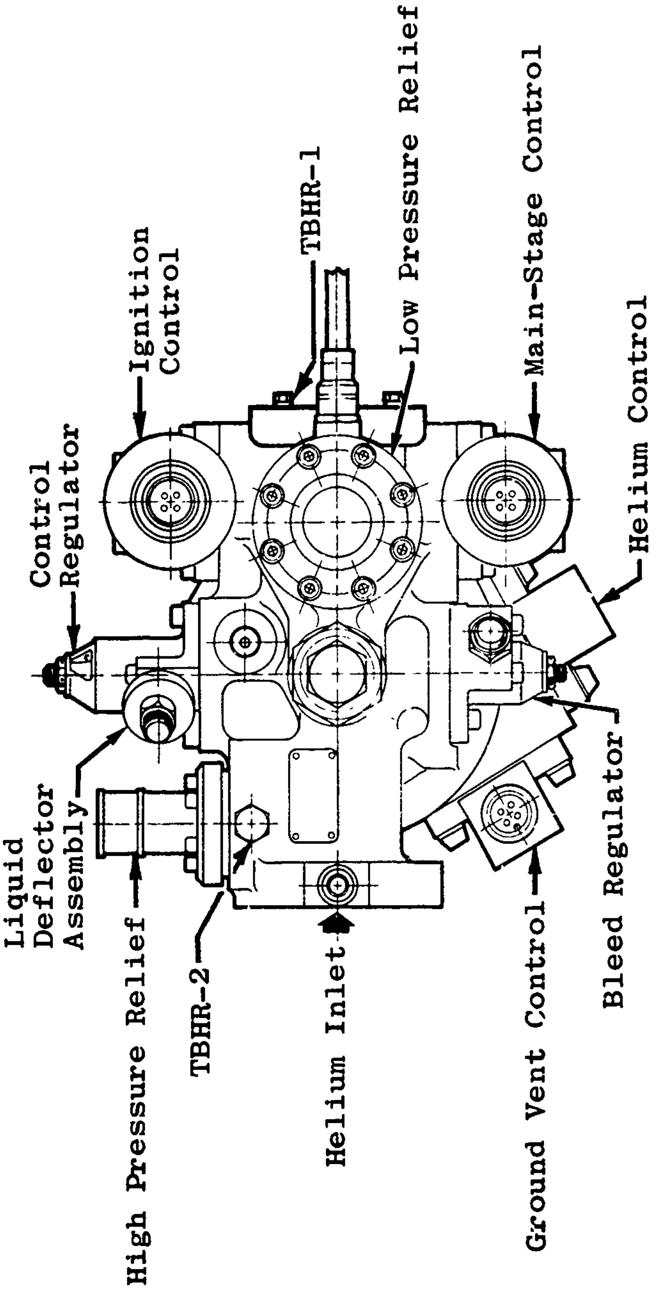
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

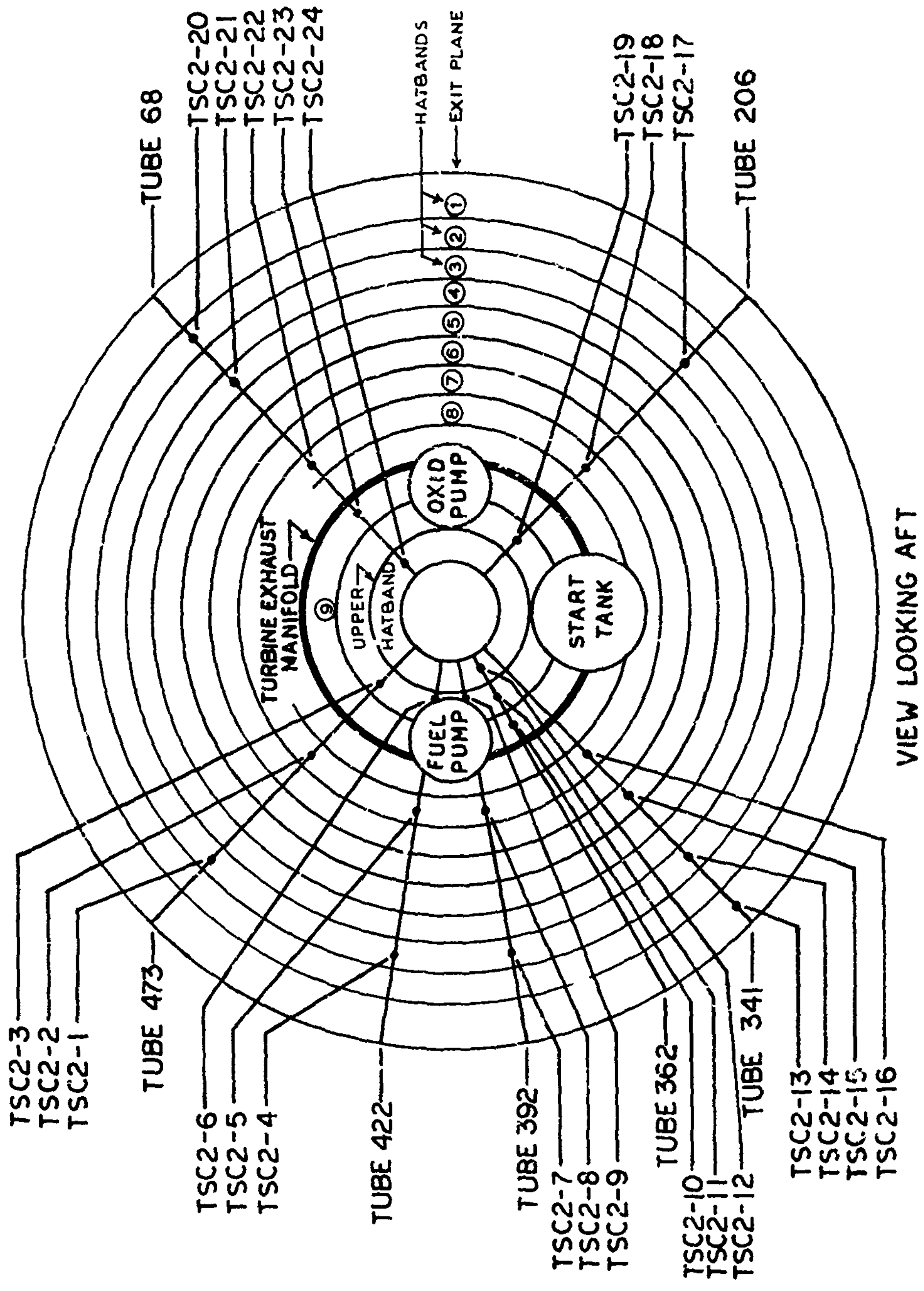


d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulator
Fig. III-1 Continued



f. Thrust Chamber
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATION
(Performance Program)

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{G_F} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$
$$P_{IF} = 30 \text{ psia}$$
$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$
$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$
$$T_{IO} = -295.212\,°F$$
$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$
$$K_4 = 144$$
$$\rho = \text{National Bureau of Standards Values } f\,(P,T)$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$
$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$
$$h_{OFIS} = f(P,T)$$
$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$
$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\,Y_O$$
$$\eta_{OC} = K_{40}\left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50}\left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$
$$K_{40} = 5.0526$$
$$K_{50} = 3.8611$$
$$K_{60} = 0.0733$$
$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO}\ H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO}\ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\ (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R = A_3 + B_3\ (\theta_{PUVO}) + C\ (\theta_{PUVO})^3 + D_3\ (e)^{\frac{\theta_{PUVO}}{7}}$$

$$+ E_3\ (\theta_{PUVO})\ (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_f\ W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}} \right] \frac{A_{NB} \; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f\,(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13}\, D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4{}_{TEF} \, M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4_{TIF}\, M_{H1}} \; \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, Y_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE
ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-06)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
August 22, 1967 - Interim Report

5. AUTHOR(S) (First name, middle initial, last name)
N. R. Vetter, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO OF REFS
January 1968	88	4

8a. CONTRACT OR GRANT NO AF40(600)-1200 b. PROJECT NO 9194 c. System 921E d.	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-67-215 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

10. DISTRIBUTION STATEMENT Subject to special export controls; transmittal to foreign governments or foreign nationals requires approval of NASA, MSFC (I-E-J), Huntsville, Alabama. Transmittal outside of DoD requires approval of NASA, MSFC (I-E-J), Huntsville, Alabama.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama

13. ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted on August 22, 1967 in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility, Arnold Engineering Development Center. The firings were accomplished during test period J4-1801-06 at pressure altitudes from 103,000 to 108,000 ft at engine start. The objectives of the test included the evaluation of (1) thrust chamber ignition characteristics with low augmented spark igniter mixture ratio and (2) the effects upon engine starting transients of minimum fuel pump inlet pressure and thrust chamber resistance for first orbit restarts with maximum starting energy. Satisfactory engine operation was obtained. The accumulated engine firing duration was 70.3 sec.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

DD FORM 1 NOV 65 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
rocket engines						
liquid propellants						
altitude tests						
ground test facilities						
ignition characteristics						

Security Classification